8-2022

Acute Effects of Match play Induced Fatigue on Jump Performance in Collegiate Women's Volleyball

Grayson Flora
East Tennessee State University

Recommended Citation

Flora, Grayson, "Acute Effects of Match play Induced Fatigue on Jump Performance in Collegiate Women's Volleyball" (2022). *Electronic Theses and Dissertations.* Paper 4102. https://dc.etsu.edu/etd/4102

Acute Effects of Match play Induced Fatigue on Jump Performance in Collegiate Women's Volleyball

---

A thesis

presented to

the faculty of the department of Sport, Exercise, Recreation, and Kinesiology

East Tennessee State University

In partial fulfillment

of the requirements for the degree

Master of Science in Sport Science and Coach Education

---

by

G. Trader Flora

August 2022

Kevin Carroll, Ph.D., Chair

Jeremy Gentles, Ph.D., Committee Member

Satoshi Mizuguchi, Ph.D., Committee Member

Michael H. Stone, Ph.D., Committee Member

Keywords: Vertical Jump, Fatigue, Athlete Monitoring, Volleyball

ABSTRACT

Acute Effects of Match play Induced Fatigue on Jump Performance in Collegiate Women's Volleyball

by

G. Trader Flora

This study investigated changes in maximal jump performance in response to match play induced fatigue. During six sets of tournament match play, seven National Association of Intercollegiate Athletics women's volleyball athletes accumulated a mean Player Load of 758.6±216.89 au (measured via microsensor accelerometry), and mean session rate of perceived exertion of 1184.1±363.2. Repeated measures ANOVAs were used to identify change with Hedge's *g* effect sizes used to assess magnitude of change. Short recovery stress scale results indicated elevated stress (ES=1.401 to 1.588) and decreased recovery (ES = -1.358 to -1.848) 24 hours post-match, trending towards baseline 48 hours post-match. Countermovement jump height (CMJH) decreased immediately post-match ($p<0.01$, ES= -0.216), partially recovered Post24 ($p=0.109$, ES=0.130), and fully recovered by Post48 ($p < 0.01$, ES=0.216). It was concluded that match-play may have contributed to the observable decline in post-match maximal jump performance, and CMJH testing may be an effective assessment of acute neuromuscular status.

DEDICATION

This thesis is dedicated to my family.

To the Madoles – for accepting me as one of their own, from the start. Special thanks to Darrin for being the first to expose me to exercise science. And most importantly, for being instrumental in my walk with Christ.

To Dennis and Vicky – for being my 'home away from home.' You were an integral part during the most pivotal chapter of my life to date; from transferring, to meeting Kate, figuring out what we would do after graduation, and most importantly, for helping me build the courage to take the dip. For that, I will forever be grateful.

To the Davidsons – for their constant love and support. While most people dread their in-laws, I couldn't have picked mine any better.

To my mom – who I am eternally indebted to. There's no doubt that you are to thank for getting me where I am today. You taught me what it means to sacrifice for those we love.

To my dad – the smartest man I've ever known. I thought of you constantly throughout this project. The countless life lessons you instilled upon me undoubtedly shape who I am. Thanks for setting the example by living a life of servitude; I aspire to make a fraction of the impact you had on others' lives.

And to Kate– words can't express my gratitude for you. You truly are "the good wife" from Proverbs 31:10. You are a constant blessing in all facets of my life. I'm not sure where I'd be without you, but I do know it wouldn't be as good.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following people who aided in the completion of this project:

Doc – thank you for making me question everything I think I know, and for being a constant guide.

Coach Stone – you’re an inspiration to all, and a welcoming figure in unknown territory. Thanks for setting the standard of excellence, not “just good enough.”

Dr. Carroll – for the guidance and direction throughout my first endeavor in research; you certainly helped me avoid countless pitfalls. Throughout this project I’ve learned more about the research process than I ever would have guessed existed.

Dr. G – for always being accessible, even on the other side of the planet. You helped me grasp the more difficult concepts and consistently provided a voice of reason throughout this project. Thanks to you and Coach C for bringing me to ETSU.

Dr. Mizuguchi – throughout this process I constantly thought to myself, “What would Satoshi think?” Thanks for that; it influenced me to do better.

Mark South – for being the grease in the wheels.

Lastly, to my classmates – for the fellowship, support, and knowledge. It’s hard to quantify just how much I’ve learned from you all. You’re a huge part of the reason the Center of Excellence is so phenomenal. I especially want to thank Michelle, Emmanuel, Fionna, Ben, and Fish for their direct help in this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1. Introduction

The sport of volleyball has drastically increased in popularity since its inception in 1895. Currently, more than 800 million people participate in the sport of volleyball worldwide (Hopkinson et al., 2016). Volleyball's popularity has recently experienced rapid growth in the United States. More than 46 million Americans take part in the sport annually (Hopkinson et al., 2016). Volleyball recently surpassed basketball as the most popular American high-school sport for females (Hopkinson et al., 2016).

Volleyball has been defined as an intermittent sport consisting of high intensity actions with considerable demands placed on the neuromuscular (NM) system (Duarte et al., 2019; Gabbett & Georgieff, 2007; Künstlinger et al., 1987). During match play, athletes perform intense and repetitive vertical jumps, landings, accelerations, changes of direction, and dives (Pelzer et al., 2020; Sheppard et al., 2008). Lower body mechanical power output has been identified as a key attribute for volleyball performance, as it may aid in the execution of common volleyball movements (Lidor & Ziv, 2010; Sheppard et al., 2008). Of these movements, vertical jump (VJ) ability is especially important (Barnes et al., 2007; Fry et al., 1991; Lidor & Ziv, 2010), as VJs are utilized in fundamental defensive and offensive actions including blocking and hitting, respectively (Brazo-Sayavera et al., 2017). Jump height (JH) has been identified as a differentiating factor in volleyball competition level (Barnes et al., 2007; Fleck et al., 1985; Smith et al., 1992; Spence et al., 1980) and a predictor of success in a United States Volleyball Association National Tournament, women's open division (Gladden & Colacino, 1974). Considering the importance of jumping for success in volleyball, regularly monitoring VJ alterations in volleyball athletes should be performed.

Considering the high intensity nature of the sport, it is possible the neuromuscular (NM) system may be fatigued from match play (Boyas & Guével, 2011; Kamandulis et al., 2016; Skurvydas et al., 2002). NM fatigue can negatively affect jumping ability (Kamandulis et al., 2016; Skurvydas et al., 2002; Watkins et al., 2017), further compounding the importance of monitoring VJ performance in volleyball athletes.

Several longitudinal studies have concluded that VJ performance is largely maintained in collegiate women's volleyball (WVB) athletes throughout a competitive season (Carroll et al., 2019; Pascal, 2020; Sanders et al., 2018). However, there is a lack of published evidence measuring acute VJ performance changes in collegiate WVB athletes, particularly concerning recovery after match play. Several studies investigating acute performance changes in different levels of men and women volleyball players reported mixed results as to the magnitude, duration, and mode in which fatigue is expressed (Brazo-Sayavera et al., 2017; Pelzer et al., 2020; Magalhães et al., 2011). The divergent results may be due to difference in participants (sex, competition level), sport (indoor court versus sand volleyball), and intervention design (practice versus match play).

Therefore, the purpose of this study was to expand upon the current shortcomings in related literature. This thesis investigated the acute changes in maximal jump performance after match play in collegiate women's volleyball. The results of this study can improve the current understanding of the physical response to WVB match play along with the time course of recovery. Additionally, the findings began to establish an effective acute athlete monitoring system which can be utilized by sport scientists and coaches alike. This can be especially useful as volleyball teams often practice multiple times between matches in the same week.

Chapter 2. Comprehensive Literature Review

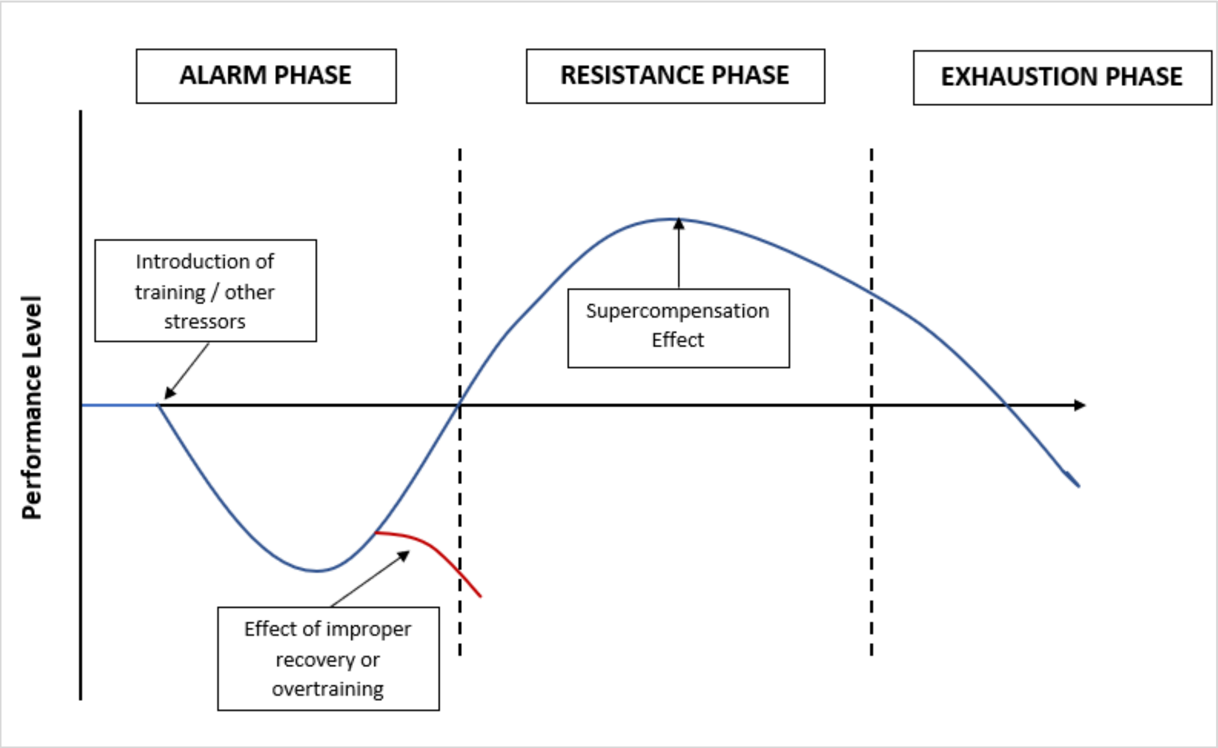
The Training Process & Athlete Monitoring

The goal of the athlete training process is to elicit positive adaptations that improve athletic performance. This is accomplished by preparing the athlete technically, tactically, psychologically, and physically (Stone et al., 2007). Training involves many variables which influence adaptation (DeWeese et al., 2015; Plisk & Stone, 2013; Suarez et al., 2019; Suchomel et al., 2018; Travis et al., 2020; Wernbom et al., 2007). The training program should be tailored to the requirements of the athlete, demands of the sport, and constraints of the sport schedule. For example, a program to develop strength may be particularly useful in untrained and weaker athletes (Suchomel et al., 2016). The program should be designed to develop specific characteristics beneficial to performance in sport (Suarez et al., 2019). Additionally, the training process is a long-term endeavor, which may be divided into phases or periods that complement the sport schedule (DeWeese et al., 2015; Plisk & Stone, 2013; Stone et al. 2021).

The training process is broadly based upon the understanding of stress-response. One pillar of this concept is Selye's model of stress & adaptation "The General Adaptation Syndrome" (Selye, 1946), in which an overloading stimulus is first applied (DeWeese et al., 2015), initiating the alarm phase, which is followed by a period of adaptation (Cunanan et al., 2018) (Figure 1.1). If the training process is designed with inappropriate stimulus or recovery, maladaptation can occur (Cunanan et al., 2018). Improper program design can result in stagnation, acute negative adaptation, or chronic negative adaptation (Cunanan et al., 2018; Stone et al., 1991; Stone et al. 2021). Positive adaptation can occur provided proper stimulus and recovery are provided. Selye described this as the resistance stage (Selye, 1946). This process of positive adaptation is also referred to as the supercompensation effect (Haff & Triplett, 2021; Zatsiorsky & Kramer, 2006) as the athlete expresses enhanced fitness, known as "realization" (Cunanan et al., 2018). If excess time passes without proper stimulation, performance can return to or fall below baseline, termed the exhaustion phase (Cunanan et al., 2018).

Figure 2.1

The General Adaptation Syndrome



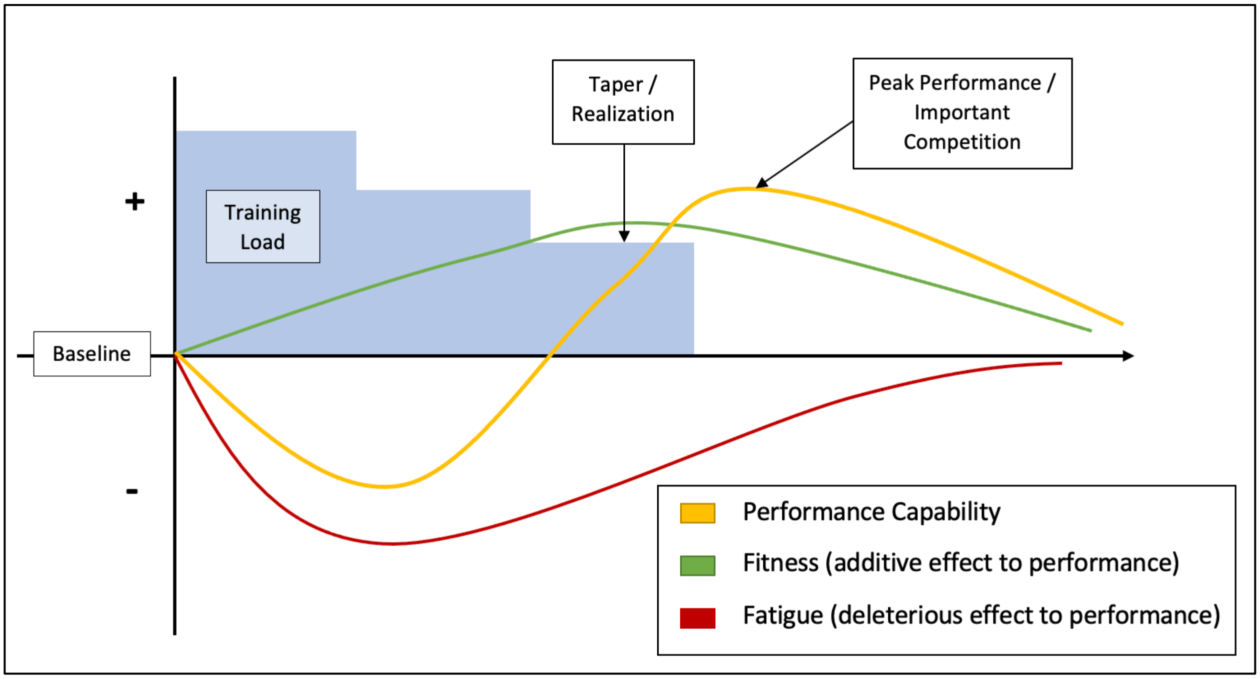
Modified from: Cunanan et al. (2018) and Haff & Triplett (2021).

The training process is additionally based upon the fitness-fatigue paradigm, originally proposed by Morton et al. (1990). The model proposes two effects of training - fitness and fatigue - which can be summated to predict performance capability (Chiu & Barnes, 2003;

Morton et al., 1990) (Figure 1.2). General fitness aiding performance in strength power sports may include muscle cross sectional area, fiber type composition, advantageous muscle architecture, neural adaptations, force production capabilities, and muscular enzyme concentrations (Chiu & Barnes, 2003; Suchomel et al., 2016; Travis et al., 2020; Stone et al. 2021). The fatigue response from training stimuli provides a deleterious effect to performance. Peak performance can be observed when fitness characteristics remain high, and fatigue is reduced.

Figure 2.2

The Fitness-Fatigue Paradigm



Modified from: Chiu & Barnes (2003), Plisk and Stone (1991), and Stone et al. (2021).

Using a broad understanding of the GAS and Fitness-Fatigue model, the training process can be strategically designed to promote realization of fitness and reduction of fatigue at optimal periods, such as important competitions (Cunanan et al., 2018). This is often accomplished by a taper, where temporarily reducing training volume or intensity in the period immediately before competition reduces fatigue and allows the athlete to display peak performance levels (DeWeese et al., 2015; Plisk & Stone, 2013; Stone et al. 2021).

Athlete monitoring programs can be initiated in order to monitor the response to training (adaptation and fatigue). The data collected can be used by coaches and sport science staff to inform the training process. The fundamental objective of monitoring is to increase performance and reduce the occurrence of long-term maladaptation or even injury (Foster, 1998; Halson, 2014; Taylor et al., 2012). Sport coaches and sports science staff have implemented numerous methodologies of athlete monitoring: subjective internal load / wellness surveys, objective internal load monitoring (e.g., heart rate), external load monitoring (e.g., Global Positioning Systems, accelerometry), physical performance assessments (e.g., maximal jump tests, sprint tests, strength assessments such as the Isometric Mid-Thigh Pull), sport specific tests, and monitoring of sport performance (Stone et al., 2019; Taylor et al., 2012). Executed appropriately, the information attained from athlete monitoring can be exceptionally valuable in informing coaching decisions, including implementation of appropriate training loads and methods.

Fatigue: Potential Sites and Causes

Fatigue has been defined as the reduction in force generation ability (Bigland-Ritchie & Woods, 1984), the failure to maintain force at the required level (Edwards, 1981), or impaired motor performance (Bigland-Ritchie & Woods, 1984). Fatigue is a complex phenomenon that can be caused by a variety of stressors, ranging from various modes of physical exercise to inadequate sleep (Kamandulis et al., 2016). A common indicator of bioenergetic processes related to fatigue is the onset of blood lactate accumulation (OBLA) (Sahlin, 1986; Westerblad et al., 2002). Other mechanisms such as neuromuscular fatigue play an important role in fatigue experienced when OBLA is not reached.

Neuromuscular (NM) fatigue has two primary categorical components; “central fatigue” and “peripheral fatigue.” Central fatigue signifies a decrease in the ability to voluntarily activate motor units due to alterations in the nervous system proximal to the neuromuscular junction (NMJ) (Boyas & Guével, 2011). Central fatigue may occur due to lack of activation in the primary motor cortex, decreased propagation from the central nervous system (CNS) to the motor units, or decreased activation of the motor units (Boyas & Guével, 2011). While not fully understood, supraspinal fatigue may be related to levels of neurotransmitters such as dopamine and serotonin (Nybo & Secher, 2004), ammonia created from deamination of amino acids during exercise (Nybo et al., 2005), and altered glycogen levels (Dalsgaard et al., 2002; Nybo, 2003). Subcortical nerual fatigue can be attributed to either a reduced corticospinal impulse to the motor neurons, or inhibitory afferent feedback from the muscle, repressing excitability at the cortical level or the spinal cord (Boyas & Guével, 2011; Davis & Bailey, 1997). Group III and IV muscular afferent pathways may be stimulated by several exercise induced mechanisms including ischemia and hypoxemia (Lagier-Tessonnier et al., 1993). Stimulation of these afferent pathways may inhibit alpha motor neuron activity (Boyas & Guével, 2011). Several biochemical sources are likely related to CNS fatigue. Alterations in neurotransmitter level and function including serotonin, acetylcholine (ACh), and dopamine may reduce propagation of nervous signaling during CNS fatigue (Davis & Bailey, 1997). Exercise released ammonia could additionally impact CNS function (Dalsgaard et al., 2002; Davis & Bailey, 1997).

Peripheral fatigue denotes repressed propagation of action potentials at or beyond the NMJ, inhibited excitation contraction coupling, or reduced contractile ability of the muscle fibers (Boyas & Guével, 2011). Fatigue induced inefficiencies at the NMJ may include alterations in ACh levels and functioning of ACh receptors (Magleby & Pallotta, 1981). Additional effects of fatigue may occur due to changes in the intracellular environment or changes within the muscle fibers. Fatigue may be caused due to alterations in calcium release from the sarcoplasmic reticulum or repressed binding of calcium to troponin (Allen et al., 1992). Intracellular concentrations of hydrogen ions and inorganic phosphate accrued during exercise appear to be leading causes of reduced force generating ability in the muscle fiber when fatigued (Westerblad et al., 1997; Westerblad et al., 2002). Muscle fibers may be directly disturbed from intense exercise. Lauritzen et al. (2009) observed severe disruptions to the z disks and myofibrils as a result of heavy eccentric exercise, which could likely limit the contractile ability in the active tissue.

Acute decreases in performance (such as muscular force production and jump height) have been observed as a result from repetitive high intensity NM exercise, including drop jumps (Kamandulis et al., 2016; Linnamo et al., 1997; Skurvydas et al., 2002; Strojnik & Komi, 1998). Considering the damaging effect of eccentric exercise (Lauritzen et al., 2009), it is possible that repeated landing impacts, consisting of intense eccentric muscle actions, may be the source of observed fatigue (Kamandulis et al., 2016; Skurvydas et al., 2002).

Volleyball: Sport and Considerations

Volleyball has been defined as a sport with intermittent, high intensity actions with considerable demands placed on the NM system (Duarte et al., 2019; Gabbett & Georgieff, 2007; Künstlinger et al., 1987). During match play athletes undergo intense and repetitive vertical jumps, landings, accelerations, changes of direction, and dives (Pelzer et al., 2020; Sheppard et al., 2008). Volleyball players do not reach the onset of blood lactate accumulation (OBLA) during match play, as they are given ample rest time between high intensity playing sessions (Künstlinger et al., 1987; Mroczek et al., 2011). Therefore, blood lactate concentrations are likely not a factor affecting volleyball performance (Magalhães et al., 2011). Considering the high intensity nature of the sport, it is probable that the NM system is the sight of fatigue resulting from match play and could therefore hinder performance.

Lower body explosive ability has been identified as a crucial attribute for volleyball performance, as it may aid in the execution of typical volleyball movements (Lidor & Ziv, 2010; Sheppard et al., 2008). The importance of vertical jump (VJ) ability in volleyball athletes is well understood (Barnes et al., 2007; Fry et al., 1991; Lidor & Ziv, 2010). Vertical jumping is used in integral volleyball defensive and offensive actions including blocking and hitting, respectively (Brazo-Sayavera et al., 2017). Jump height (JH) has been identified as a differentiating factor in volleyball competition level (Barnes et al., 2007; Fleck et al., 1985; Smith et al., 1992; Spence et al., 1980) and a predictor of success in a United States Volleyball Association National Tournament, women's open division (Gladden & Colacino, 1974). Considering NM fatigue can negatively affect jumping ability (Kamandulis et al., 2016; Skurvydas et al., 2002; Watkins et al., 2017), it is prudent to monitor jump performance in volleyball.

Vertical Jump Testing

Vertical jump testing is regularly used in athlete monitoring and has been researched extensively. A survey of coaches and sport scientist staff in high performance sport found jump testing to be the most commonly used assessment in monitoring programs (Taylor et al., 2012).

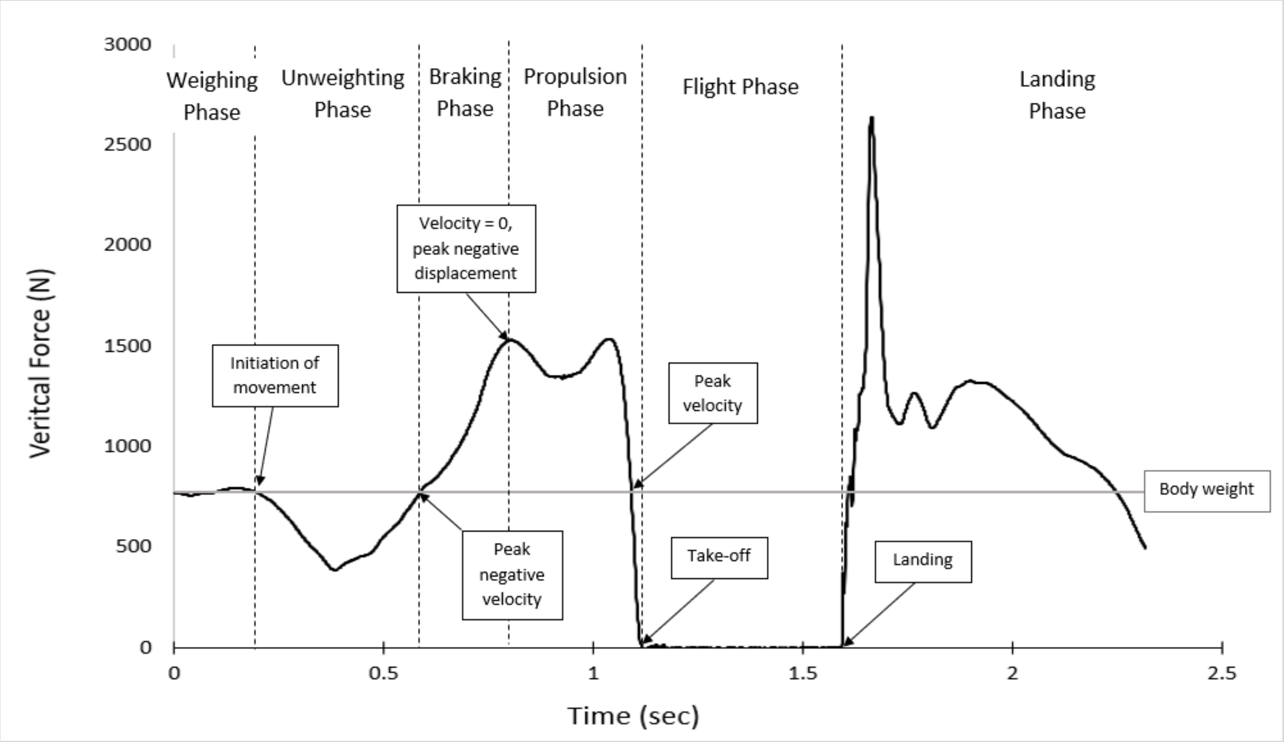
A recent meta-analysis by Claudino et al. reviewed 151 peer reviewed papers investigating the use of the countermovement jump (CMJ) as a tool to monitor neuromuscular status (Claudino et al., 2017). Studies included in the meta-analysis represented investigations with a wide age range of participants (8 ±1 to 82 ± 3 years old) with a pooled sample mean of 23 ± 12 years. 60% of the studies included specifically investigated athletes, participating in 21 different sports, with soccer (49%), basketball (10%), track and field (8%), and volleyball (5%) being the most common. Throughout the 151 included studies, Claudino et al. (2017) identified 63 different CMJ kinetic variables used by researchers. As a secondary goal of the meta-analysis, Claudino et al. (2017) statistically assessed the compiled studies' kinetic variables for reliability and ability to detect change in NM status. The authors found that countermovement jump height (CMJH) averaged between trials intrasession was more representative of performance than using only the highest CMJH trial in monitoring NM status. In fact, they found that averaging intra-session trial results for all kinetic variables revealed more accurate performance changes (Claudino et al., 2017). Additionally, the authors found that the following variables were suitable for detecting positive adaption effects following a training intervention: peak power (PP), mean power (MP), peak velocity (PV), peak force (PF), mean impulse, and PP calculated by equations using CMJH and body mass. These results were based on the following practical applications for best practice of monitoring NM status via CMJ:

> - Averaged CMJ performance without arm swing should be used to track neuromuscular status.
> - Average CMJ height was more sensitive than highest CMJ height to monitor changes in neuromuscular status.
> - Variables used to monitor neuromuscular status should have a small-moderate coefficient of variation (CV) and a moderate-large effect size (ES). (Claudino et al., 2017, p. 401)

Characteristics of the CMJ force-time (F-T) curve have been extensively researched. The CMJ is typically divided into the weighing, unweighting, braking, propulsion, flight, and landings phases (McMahon et al., 2018) (Figure 1.3). The weighing phase (also referred to as the stance phase or silent phase) consists of no movement, as the athlete stands as still as possible (McMahon et al., 2018). This phase is utilized to establish a static system weight, where accuracy is essential for determining start of the counter movement and calculation of jump kinetics and kinematics (McMahon et al., 2018; Mizuguchi et al., 2015). The unweighting phase begins as the athlete initiates the countermovement by relaxing agonist muscles, creating a downward displacement of the center of mass (COM), resulting in a net force less than that of system mass. (McMahon et al., 2018). The unweighing phase ends as net force returns to baseline, indicating peak downward velocity has been reached (McMahon et al., 2018). At this point, the braking phase begins, as the athlete begins to decelerate their downward descent. This phase has also been described as the "eccentric phase," as the jumping agonist muscles work eccentrically the brake the downward acceleration (McMahon et al., 2018). Peak force is typically found during this phase. The braking phase continues until negative velocity reaches zero; this point additionally indicates the greatest negative displacement of COM (McMahon et al., 2018). The propulsion phase begins as the athlete's COM obtains a positive, upwards velocity. A hypothetical momentary pause between the braking and propulsive phases of the CMJ - termed the amortization phase – exists as the athlete transitions from eccentric to concentric muscle action and the COM briefly remains stationary (McMahon et al., 2018). Upwards velocity is accomplished as the athlete's hip, knee, and ankle extensors begin to concentrically push the COM upwards (McMahon et al., 2018). This phase ends at take-off, as the athlete's feet leave the ground, and net force equals zero, beginning the flight phase (McMahon et al., 2018). Before the athlete lands, they often "tuck" their legs by flexing the joints, in anticipation of the landing (McMahon et al., 2018). This change in joint position can cause overestimation in flight time. As the athlete's feet touch the ground, the landing phase begins, and the athlete produces force to brake their landing, stopping their downward deceleration caused by gravity.

Figure 2.3

Phases and Landmarks of the Countermovement Jump



Modified from: McMahon et al. (2018) and Mizuguchi (2012).

Several valuable metrics can be derived from the CMJ F-T curve, including acceleration, velocity, and displacement (McMahon et al., 2018). This can be accomplished by a set of calculations often referred to as “forward dynamics” (McMahon et al., 2018). The calculations are fundamentally based on Newton’s low of acceleration, which can be mathematically expressed as follows:

$\Sigma F = m*a$ (equation 3.22) (McGinnis, 2013, p. 102)

Where F = force, m = mass, and a = acceleration. Assuming that mass remains constant throughout the jump, acceleration can be calculated by dividing the net force-time record by the athlete's body mass (McMahon et al., 2018). Considering acceleration is the time-derivative of velocity, velocity can be calculated by integrating the acceleration-time curve between two timepoints. Further considering velocity is the time-derivative of displacement, COM displacement can be calculated by integrating the velocity–time curve between two timepoints.

Considering acceleration is equal to change in velocity divided by change in time, an alternative equation for force can be expressed as:

$\Sigma F = m(\Delta v/\Delta t)$ (equation 3.7) (McGinnis, 2013, p. 102)

Where v = velocity and t = time.

During the CMJ, athletes apply force over a span of time (Mizuguchi, 2012). The product of force over a length of time is impulse (McGinnis, 2013, p. 102). By multiplying both sides of the above equation by time, the impulse-momentum relationship is produced (Descarte, 1644; Newton 1729), which is mathematically expressed as follows:

$\Sigma F{*}\Delta t = m{*}\Delta v$ (equation 3.7) (McGinnis, 2013, p. 102)

Considering impulse (force multiplied by time) can be graphically calculated during a CMJ, and athlete mass is assumed to be constant during a CMJ, take off velocity can be ascertained (Mizuguchi, 2012). Take-off velocity can then be used to calculate a theoretically perfect JH using the laws of constant acceleration, considering gravity is a constant accelerant (Mizuguchi, 2012). This method of calculating JH, known as "$\mathrm{JH}_{\mathrm{IMP\text{-}MOM}}$" is therefore recommended as opposed to JH calculated from F-T, "$\mathrm{JH}_{\mathrm{F\text{-}T}}$" (Moir, 2008).

A recent study by Ishida et al. (2021) demonstrated the usefulness of acute CMJ testing to assess NM status in Division 1 (D1) women's soccer athletes. Ishida et al. (2021) measured changes in maximal jump performance in unloaded and loaded (20 kg barbell) CMJs 3 hours before a match (Pre), 12 hours after the match (Post12), and 38 hours after the match (Post38). Researchers observed statistically significant moderate to large decreases from Pre to Post12 in unloaded CMJ variables, including: CMJH, reactive strength index (RSI), concentric impulse (CI), PP, relative peak power (rPP), and concentric average power (Ishida et al., 2021). Statistically significant moderate to large decreases were also observed in loaded CMJ variables: RSI, eccentric impulse (EI), CI, PP, rPP, and CAP (Ishida et al., 2021). However, there were no statistically significant differences in any CMJ variables between Pre and Post38. The researchers concluded that both CMJH and PP are viable measures of acutely assessing NM status in the studied population (Ishida et al., 2021). Additionally, the results of the study were used to determine the time course of recovery for NM status after a collegiate women's soccer match. The researchers indicated that 38 hours may be sufficient time to return to baseline NM status following a collegiate women's soccer match (Ishida et al., 2021). Considering several matches often take place within a week, with practices interspersed between games (Ishida et al., 2021), understanding the predicted time course of NM recovery could be instrumental as the coaching staff plans the training week. Furthermore, acute athlete monitoring throughout the week could have additional benefit to the coaching staff, providing them with real-time updates on athlete status, further informing the training process.

Longitudinal WVB Monitoring Studies

Several studies have monitored jump performance longitudinally in WVB. A thesis study by Pascal (2020) monitored a NCAA D1 WVB team throughout a preseason and competitive season. The study by Pascal (2020) was divided into 4 distinct time-points: preseason (PS), (in-season non-conference (ISNC), 1st half of conference play (ISC1) and 2nd half of conference play (ISC2). Athletes wore a VERT (Vert, Fort Lauderdale, FL) inertial measurement unit (IMU) with a 3-axis accelerometer and 3 axis gyroscope every practice throughout all timepoints. Before the first practice of every week, starting at ISNC, athletes underwent CMJ testing on a switch mat (Probotics Inc, Huntsville, AL), which calculated jump height from flight time. In contrast to the recommendation by Claudino et al. (2017), athletes were allowed to use an arm swing when jump mat testing (Pascal, 2020). No information was provided on the numbers of CMJ test trials recorded each session, or if the results were averaged. No statistically significant differences in average jump height (VERT), total jumps over 50.8 cm (VERT), average highest jump, or maximal jump mat height were observed between any periods (Pascal, 2020). Effect sizes were not reported in the paper. Effect sizes using Hedge's *g* were calculated from PS baseline using the means and standard deviations provided. Results yielded trivial changes in average jump height (VERT) until a moderate increase during ISC2 ($p = 0.221$ $g = 0.65$), trivial decreases in total jumps over 50.8 cm (VERT) in all periods until a small decrease during ISC1 ($p = 1$, $g = -0.27$), small increases in average highest jump (VERT) (ISNC: $p = 1$, $g = 0.22$, ISC1: $p = 1$, $g = 0.20$, ISC2: $p = 1$, $g = 0.45$), and trivial changes in maximal jump mat height. Pascal (2020) concluded that jump performance was maintained throughout the course of the season. Effect size analysis indicates that jump performance was maintained throughout the season, and possibly slightly increased during ISC2 match play. While these findings elucidate the chronic response to a collegiate WVB season, they do not provide insight on acute (e.g., daily) changes in jump performance.

This longitudinal evidence is further supported by Carroll et al. (2019), who found little variation in CMJH among a D1 WVB team throughout a 14-week season. Athletes underwent CMJ testing twice weekly on portable force plates sampling at 1,000 Hz (PASCO, Roseville, CA, USA). CMJ testing procedures aligned with the recommendations by Claudino et al. (2017); athletes performed two jump trials every session while holding a Polyvinyl Chloride (PVC) pipe on their upper back (removing arm swing) - the trials were averaged for longitudinal comparison (Carroll et al., 2019). Excellent intrasession reliability was observed for CMJH (ICC = 0.94) and Reactive Strength Index-modified (RSI_{MOD}) (ICC = 0.93), while good reliability was found for rPP (ICC = 0.79), and moderate reliability for countermovement depth (CMDepth) (ICC =0.61) (Carroll et al., 2019). Intersession reliability was again excellent for CMJH (ICC = 0.92) and RSI_{MOD} (ICC =0.92), but poor for rPP (ICC = 0.41) and CMDepth (ICC = 0.39) (Carroll et al. 2019). The authors concluded that CMJH was maintained throughout the season (Carroll et al. 2019), which is in line with the research from Pascal (2020). Practically, the authors suggest that CMJH may be used to monitor chronic adaptations to training, whereas acute fatigue may have been detected by rPP and CMDepth, explaining the differences between intrasession and intersession reliability (Carroll et al. 2019).

In a case study by Sanders et al. (2018), a National Collegiate Athletic Association (NCAA) Division I (D1) women's volleyball (WVB) female outside hitter was monitored throughout a competitive season. Jump performance and external training load were monitored via a microsensor device including a gyroscope, magnetometer, and tri-axial accelerometer sampling at 100 hz every match and practice. The athlete's weight and approach jump (AJ) (a sport specific jump test with three or four steps leading into a maximal effort vertical jump) were measured before the season as a baseline, and 48 hours after every match (Sanders et al., 2018).

The best of three AJ trials was recorded (Sanders et al., 2018), in contrast to the recommendation by Claudino et al. (2017) to average the trials. The athlete's power output from the AJ was estimated based off Sayer's equation (Sanders et al., 2018; Sayers et al., 1999). Match play statistics including hitting percentage, blocks, kills, digs, wins and losses were also recorded. The researchers observed that the athlete's body weight and absolute power decreased by 4.8% 3.8%, respectively, relative power increased by 1.9%, and maximal AJ height showed no change (0.0%) from baseline to final measurement (Sanders et al., 2018). The analysis indicated that medium and high intensity accelerations, low intensity decelerations, and low and high intensity jumps accounted over 90% of the variation in maximal relative AJ performance ($r = 0.958$, $r^2 = 0.917$, $p < 0.001$) (Sanders et al., 2018). Additionally, the athlete displayed a better hitting percentage in matches won versus matches lost ($p=0.05$). Lastly, the researchers observed that the athlete completed statistically significantly fewer high intensity jumps during practices that preceded matches won compared to practices preceding matches lost (Sanders et al., 2018). Combining the latter two observations, the researchers concluded that decreased high intensity jump volume may have contributed to lowered fatigue on game day, improving performance, and impacting the outcome of the match (Sanders et al., 2018). The findings regarding VJ performance from the current case study (Sanders et al., 2018) agree with the findings from Pascal (2020) and Carroll et al. (2019), indicating that jump performance is maintained throughout a competitive season in WVB. Additionally, the day-to-day findings from Sanders et al. (2018) indicate that training loads can acutely affect performance in the subsequent days. This illustrates the importance of acutely monitoring NM status in order to understand athletes' reaction to training and readiness for competition. Considering several matches often take place within a week, with practices between games, monitoring NM status could be valuable as the coaching attempts to manage fatigue and implement appropriate training loads.

Acute Volleyball Monitoring Studies

The acute effects of volleyball training sessions and matches have been previously investigated, to a minor extent. Brazo-Sayavera et al. (2017) examined the acute effects of "fatigue" induced from a scripted volleyball training session on different jump tests in WVB athletes. Participants included two groups: "Elite Group" (EG) and "Amateur Group" (AG) (Brazo-Sayavera et al., 2017). EG athletes competed in national level (Spanish Volleyball First League) and AG athletes competed in amateur level National Second Division. The "fatiguing" training intervention included 45 block jumps (BJ) - a sport specific jump where the arms are held upright during the jump - executed in 15 sets of 3 BJ. Maximal squat jump (SJ) (one second pause dividing the eccentric and concentric portions, at 90° knee flexion), CMJ, and BJ were tested pre and post intervention. Contrary to the recommendation by Claudino et al. (2017), only the best jump trial was used in analysis (Brazo-Sayavera et al., 2017). No statistically significant changes were observed from pre to post intervention in SJ ($p = 0.965$ and $p = 0.655$; $g = 0.01$ and $g = 0.09$), CMJ ($p = 0.742$ and $p = 0.211$; $g = 0.04$ and $g = 0.10$) in either group (Brazo-Sayavera et al., 2017). BJ did decrease substantially in the EG ($p = 0.043$; $g = 0.40$), but not in the AG ($p = 0.569$; $g = 0.08$) (Brazo-Sayavera et al., 2017). Brazo-Sayavera and colleagues (2017) designed the "fatiguing" intervention to reflect the average amount of jumps and landings an athlete would experience in two "games", based on research by Tillman et al. (2004). However, it seems that inconsistent terminology usage has caused some confusion amongst the literature; Tillman et al. (2004) refer to periods of a single match as "games." In this definition, several "games" make up one match. These periods are typically referred to as "sets," to limit confusion. Therefore, the intervention design by Brazo-Sayavera et al. (2017) included the VJ volume from two sets of a typical match. Considering that matches consist of three to five sets, the intervention design by Brazo-Sayavera et al. (2017) does not represent VJ quantity from full match play. Additionally, the intervention did not include other integral aspects of typical volleyball matches including sprinting, diving, rapid changing of direction, and other types of jumps including AJ and spike jump (Pelzer et al., 2020; Sheppard et al., 2008). Therefore, the study design by Brazo-Sayavera et al. (2017) likely did not equate to the external training load expected from a WVB match and was not powered to produce fatigue similar to that of exhaustive match play. This may explain the lack of changes in jump height in the study.

The relationship between external training load, internal training load, markers of fatigue, and maximal jump performance in elite youth beach volleyball athletes was recently studied (Pelzer et al., 2020). Two male and five female athletes (18.9 ± 1.3 years) competing in the highest national level of either under 19 or under 23 years old at the German national training center boarding school participated in the study. External training load was measured via VERT microsensor and video recording in three different practice types: practice type A was predominantly based on jumping, type B involved moderate volumes of jumping and diving, and type C was diving and follow up action focused. Pre and post intervention testing included: CMJ with no arm swing on stable surface via Optojump (Optojump Next, Microgate, Bolzano, Italy), BJ and spike jump on sand via VERT microsensor, delayed onset of muscle soreness (DOMS), and creatine kinase levels (CK). DOMS and CK were measured 30 and 15 minutes post-training, respectively, and again at 48 hours post training. Rate of perceived exertion (RPE) was measured on a scale of 1-10 with 10 reflecting total exhaustion, and then multiplied by session duration to calculate session rate of perceived exertion (sRPE). Significantly higher sRPE was observed after practice type C (diving dominant) than A (jumping dominant) (Pelzer et al., 2020). Pre-post changes in DOMS were significantly higher in practice type C than type A, and no significant changes were found pre-post in type A (Pelzer et al., 2020). Significant changes in CK pre to post intervention were found for all practice types, with no statistically significant differences between practice types; however, the authors did note a trend towards larger response inversely related to jump volume (Pelzer et al., 2020). Interestingly, non-significant increases in CMJ performance pre to post intervention were observed in all practice types (ES = 0.18 to 0.30). (Pelzer et al., 2020). The authors theorize this finding may be related to a post activation potentiation effect, or a sign of low NM fatigue, despite the changes in internal load and indirect markers of muscle damage (Pelzer et al., 2020). Irrespective of CMJ performance, the researchers suggest that solely monitoring jump volume to assess training load in beach volleyball may be insufficient, as activities such as diving may have a larger effect on fatigue (Pelzer et al., 2020). This evidence is in line with findings from Sanders et al. (2018), who found that accelerations and decelerations account for a substantial portion of variation in AJ height. Further, the authors note the limitations of comparing findings from beach volleyball to court volleyball, as the instable playing medium and game characteristics vary, potentially altering the activity and response to match play (Pelzer et al., 2020).

The acute impact of beach volleyball match play on NM status has been investigated in internationally competitive elite Portuguese males (Magalhães et al., 2011). Participants underwent the following testing procedures immediately pre, immediately post, and three hours after several matches in a one day tournament: three CMJ trials with arm swing testing on a Bosco jump mat (Ergojump, Globus, Italy), two laser timed sprint trials with splits at 7.5 and 15 m, three maximal isometric voluntary contraction (MIVC) trials of dominant leg knee flexors (hip angle of 0°, knee angle of 90°) and extensors (hip angle of 90°, knee angle of 90°) using a isometric dynamometer. The best trial of each test was recorded, in contrast to recommendations by (Claudino et al., 2017). Capillary blood samples from the earlobe were drawn during the match to analyze blood lactate levels. Blood lactate increased significantly during match play (baseline: 0.95 ± 0.23 mM, match play: 2.30 ± 0.46 mM), but returned to baseline by 3 hours post-match (Magalhães et al., 2011). CMJH was not affected substantially 0 or 3 hrs. after the match (Magalhães et al., 2011). However, 7.5m and 15m sprint ability significantly decreased at 0 hrs. post (~3 and 3.6%, respectively) and 3 hrs. post (~2% and 2.5%, respectively) (Magalhães et al., 2011). Knee extension and flexion MIVC was significantly decreased at 0 hrs. post-match (-19% and -17%, respectively) (Magalhães et al., 2011). MIVC returned to baseline at 3 hrs. post-match. The observed blood lactate results are in line with research by Mrozcek et al. (2011) and Künstlinger et al., (1987), suggesting that volleyball athletes do not reach OBLA during match play. Despite the absence of OBLA, some performance markers of fatigue were observed as a result of match play. The sprint and MIVC results indicate that there was a decrease in NM status immediately post-match, but that the athletes were at least partially recovered by the 3-hr. time point. These results do not align with the lack of changes observed in CMJ performance, to the authors' surprise. The authors suggest that the sprint and MIVC findings indicate decreased NM performance may have been possible late in the match, but the CMJ testing wasn't sensitive to detect the changes. This may be due to the testing methodology, which is inconsistent with the recommended methodology (elimination of the arm swing, averaging of trials) proposed by Claudino et al. (2017).

Alternatively, the lack of changes in jump performance observed in the acute volleyball research may be due to altered jump strategies. A simulation study determined jump height does not increase with increases in muscular force production alone; the increased force production must be accompanied by a complimentary reorganization of activation patterns (Bobbert & Van Soest, 1994). Rodacki et al. (2002) directly investigated the topic by measuring changes in jump performance and strategy in fatigued conditions. The authors theorized that jumping performance may be inhibited when fatigued due to altered coordination/organization (neural input), reduced contractile capacity of the muscle, or both (Rodacki et al., 2002) After a fatiguing knee extensor intervention, decreased CMJH, lessened negative displacement of the COM, and reduced angular displacement of the knee joint were observed, indicating possible changes in the jump mechanics when fatigued (Rodacki et al., 2002). Despite decreased displacement, the jump took the same duration to complete, indicating decreased COM velocity throughout the eccentric and concentric portions of the CMJ (Rodacki et al., 2002).

Similarly, Gathercole et al. (Gathercole et al., 2015) reported changes in different CMJ kinetic variables after a fatiguing protocol. 24 and 72 hrs. post intervention, small to moderate PP, eccentric duration (EccDur), concentric duration (ConDur), total duration (TotDur), flight time: contact time (FT:CT), time to peak force and power, were observed (Gathercole et al., 2015). The authors suggest these results indicate changes in movement strategy, even at time-points when jump height was not significantly affected, which may yield a useful strategy to detect NM fatigue (Gathercole et al., 2015).

Conclusion

Additional research on the acute effects of match play on NM status in collegiate WVB is warranted. The purpose of the present thesis was to investigate the acute changes in maximal jump performance after match play in collegiate WVB. The results of this study can improve the current understanding of physical response to WVB match play along with the time course of recovery. Additionally, the findings aim to establish an effective acute athlete monitoring system which can be utilized by sport scientists and coaches alike.

Chapter 3. Acute Effects of Match Play Induced Fatigue on Jump Performance in Collegiate Women's Volleyball

By

G. Trader Flora

Abstract

The purpose of this study was to investigate changes in maximal jump performance in response to match play induced fatigue. During six sets of tournament style match play, seven National Association of Intercollegiate Athletics women's volleyball athletes accumulated a mean Player Load of 758.6±216.89 au (measured via microsensor accelerometry), and mean session rate of perceived exertion of 1184.1±363.2. Repeated measures ANOVAs were used to determine changes amongst timepoints with Hedge's *g* effect sizes used to assess magnitude of change. Short stress recovery scale results indicated elevated stress (127.3 - 266.7%) and decreased recovery 24 (25.8 - 33%) hours post-match, trending towards baseline 48 hours post-match. Countermovement jump height (CMJH) decreased immediately post-match ($p<0.01$, ES= -0.216), partially recovered 24 hours post-match ($p=0.109$, ES=0.130), and fully recovered by Post48 9 ($p < 0.01$, ES=0.216). No other changes in countermovement jump variables were observed. It was concluded that collegiate women's volleyball match-play may have contributed to the observable decline in post-match maximal jump performance, and CMJH testing may be an effective assessment of acute neuromuscular status.

Keywords: Vertical Jump, Fatigue, Athlete Monitoring, Volleyball

Introduction

The sport of volleyball has gained considerable popularity as 800 million people partake in the sport of worldwide, and has surpassed basketball as the most popular American high-school sport for females (Hopkinson et al., 2016). Volleyball has been defined as an intermittent sport with high intensity actions and considerable demands placed on the neuromuscular (NM) system (Duarte et al., 2019; Gabbett & Georgieff, 2007; Künstlinger et al., 1987). During match play, athletes complete intense and repetitive vertical jumps, landings, accelerations, changes of direction, and dives (Pelzer et al., 2020; Sheppard et al., 2008). Of these movements, vertical jump (VJ) ability is especially important (Barnes et al., 2007; Fry et al., 1991; Lidor & Ziv, 2010), as VJs are used in fundamental defensive and offensive actions including blocking and hitting, respectively (Brazo-Sayavera et al., 2017). Jump height (JH) has been identified as a differentiating factor in volleyball competition level (Barnes et al., 2007; Fleck et al., 1985; Smith et al., 1992; Spence et al., 1980) and a predictor of success in a United States Volleyball Association National Tournament, women's open division (Gladden & Colacino, 1974).

Fatigue has been defined as the reduction in force generation ability (Bigland-Ritchie & Woods, 1984), the failure to maintain force at the required level (Edwards, 1981), or impaired motor performance (Bigland-Ritchie & Woods, 1984). Neuromuscular (NM) fatigue has been observed as a result of high intensity exercise, causing acute decreases in performance (Kamandulis et al., 2016; Linnamo et al., 1997; Skurvydas et al., 2002; Strojnik & Komi, 1998). Due to the high intensity nature of the sport, it is plausible the NM system may be acutely fatigued from volleyball match play (Boyas & Guével, 2011; Kamandulis et al., 2016; Skurvydas et al., 2002). Further, NM fatigue can negatively affect jumping ability (Kamandulis et al., 2016; Skurvydas et al., 2002; Watkins et al., 2017). Considering the importance of VJ in volleyball combined with the potential for fatigue to affect sport performance, it is imperative to monitor NM status and VJ ability in volleyball athletes.

Athlete monitoring programs can be initiated to monitor the response to training (adaptation and fatigue). The data collected can be used by the coaches and sport science staff to inform the training process. External training load is defined as physical work completed, while internal training load is the physiological and psychological response to the external load (Taylor et al., 2012; Vlantes & Readdy, 2017). External and internal training load in collegiate women's volleyball (WVB) has been studied via microsensor accelerometers and session rate of perceived exertion (sRPE) (Vlantes & Readdy, 2017). One popular metric used to summarize external load via accelerometry data is Player Load (PL), which summates magnitude of accelerations in all three axes (Vlantes & Readdy, 2017). Athlete monitoring may additionally assess athlete performance levels. The countermovement jump (CMJ) has been demonstrated to be an acute assessment of NM status (Claudino et al., 2017).

Several longitudinal studies have concluded that VJ performance is maintained in collegiate women's volleyball athletes throughout a competitive season (Carroll et al., 2019; Pascal, 2020; Sanders et al., 2018). However, a lack of published evidence exists in studies measuring acute changes in VJ performance in collegiate women's volleyball athletes. The few studies available report mixed results as to what mode, magnitude, duration, and effect of fatigue can be expected, with limited changes in maximal jump performance. Brazo-Sayavera et al. (2017) observed minor decreases in block jump but not static or countermovement jump (CMJ) performance after a short training session in elite WVB athletes. However, external training load during the intervention was substantially less than that of a full volleyball match. This could explain the lack of changes in NM status and CMJH post intervention. Pelzer et al. (2020)

observed small, non-statistically significant increases in VJ performance after different practice sessions, despite increase in indirect markers of muscle damage and fatigue in elite male and female youth beach volleyball athletes. The authors discuss, however, the limitations of extrapolating results from beach volleyball research to court volleyball research. Magalhães et al. (2011) observed no statistically significant changes in vertical jump performance despite decreased sprint performance and maximal isometric voluntary contraction of the knee extensors and flexors post-match play in elite male sand volleyball athletes. The divergent results may be due to difference in participants (e.g., sex, competition level), sport (indoor court versus sand volleyball), intervention design (practice versus match play), and data collection methodology (jump test and procedures).

The limitations in the current body of acute monitoring research in female court volleyball athletes yields an incomplete understanding of the effects of match play on NM status in the given population. It is not clear if court volleyball match play induces fatigue sufficient to affect VJ ability in female athletes. Alternatively, there is some evidence suggesting that jump movement strategy may be altered when fatigued (Rodacki et al., 2002; Gathercole et al., 2015). It is plausible that volleyball athletes adopt an altered movement strategy to accomplish the same VJ performance when fatigued. Given the popularity of the sport and lack of acute monitoring research, further investigations are warranted.

The purpose of this study was to observe the acute changes in maximal jump performance following match play in collegiate women's volleyball. Changes in countermovement jump height (CMJH) and peak power (PP) were observed to monitor changes in NM status. Changes in eccentric phase duration (EccDur), concentric phase duration (ConDur), eccentric unloading phase impulse (EccUnImp), eccentric deceleration phase impulse

(EccDecImp) and countermovement depth (CM Depth) were observed in order to investigate signs of potential changes in movement strategies during the CMJ.

The findings can expand upon the current understanding of physical response to WVB match play along with the time course of recovery. This information can be used to inform coaching decisions regarding match preparation and recovery, as volleyball teams compete in multiple matches and training sessions each week. This is especially important, as a case study by Sanders et al. (2018) reported that a D1 WVB hitter's match performance was influenced by the external training load in preceding practices. Additionally, the study explores the effectiveness of an acute athlete monitoring system, informing future methods utilized by sport scientists and coaches aiming to acutely monitor NM status.

The following were hypothesized, based on the relevant previous literature:

- CMJH would decrease significantly from Pre to Post0
- CMJH would return to baseline by Post24
- PP would decrease from Pre to Post0
- CM depth, EccDur, and ConDur would increase Pre to Post0 & Post24
- All variables would return to baseline by Post48

Methods

Participants

Seven National Association of Intercollegiate Athletics (NAIA) women's volleyball athletes (freshmen, *n* = 3; sophomore, *n* = 1, junior *n* = 3) participated in this study (age, 20.2 ± 0.9 years [age range, 18-21 years]; height, 172.5 cm ± 5.7; body mass (BdM), 81.7 ± 16.6 kg). The inclusion criteria required participants be (a) currently training and competing in collegiate women's volleyball at the NAIA level, (b) cleared for activity by the athletic training staff at the time of competition. Data were only included in analysis for athletes who (a) competed on the day of the tournament, and (b) were on time and completed the 3 subsequent testing sessions. The testing was part of an on-going monitoring program. Prior to the study, the participants were informed of the potentials risks and benefits of participating in the study before signing a written informed consent document, as approved by the East Tennessee State University institutional review board.

Timeline

Maximal jump performance and athletes' subjective recovery were measured using CMJ and short recover stress scale (SRSS) at 4 different time-points surrounding tournament style match play: 1 hour before match (Pre), immediately upon conclusion of tournament match play (Post0), 24 hours post conclusion of match play (Post24), and 48 hours post conclusion of match play (Post48) (Figure 3.1). External training load during match play and related activity was measured via a microsensor IMU. Internal training load was assessed via RPE after the conclusion of the final match. Athletes were familiarized with all the testing procedures prior to the tournament and data collection. Athletes were instructed to refrain from alcohol, physical exercise, and ice-baths between all time-points. Data collection procedures were kept consistent throughout the time-points.

Pre-Match. 1 hour and 10 minutes before the first match, the short recovery stress scale (SRSS) survey was completed on paper. 1 hour before the match, the participants underwent a standardized dynamic warm-up. CMJ testing commenced 45 minutes before the start of the match.

Match play. The athletes participated in a normally scheduled tournament during their off-season. While the matches did not count toward the team's record, the matches were all played against other collegiate WVB teams. All matches were played according to standard NAIA rules and regulations. The tournament consisted of three matches against different teams, two sets per match, with an hour break between matches. External training load was measured using Catapult OptimEye S5 accelerometry units. Accelerometry data collection began at the onset of the pre-match warmups and continued until completion of the ensuing match. "Match play Duration" data included activity from athletes during active sessions of the match; data collection paused during intermissions, and activity was excluded during players' time on the bench. "Total Activity Duration" included activity during the warmups, in addition to match play activity.

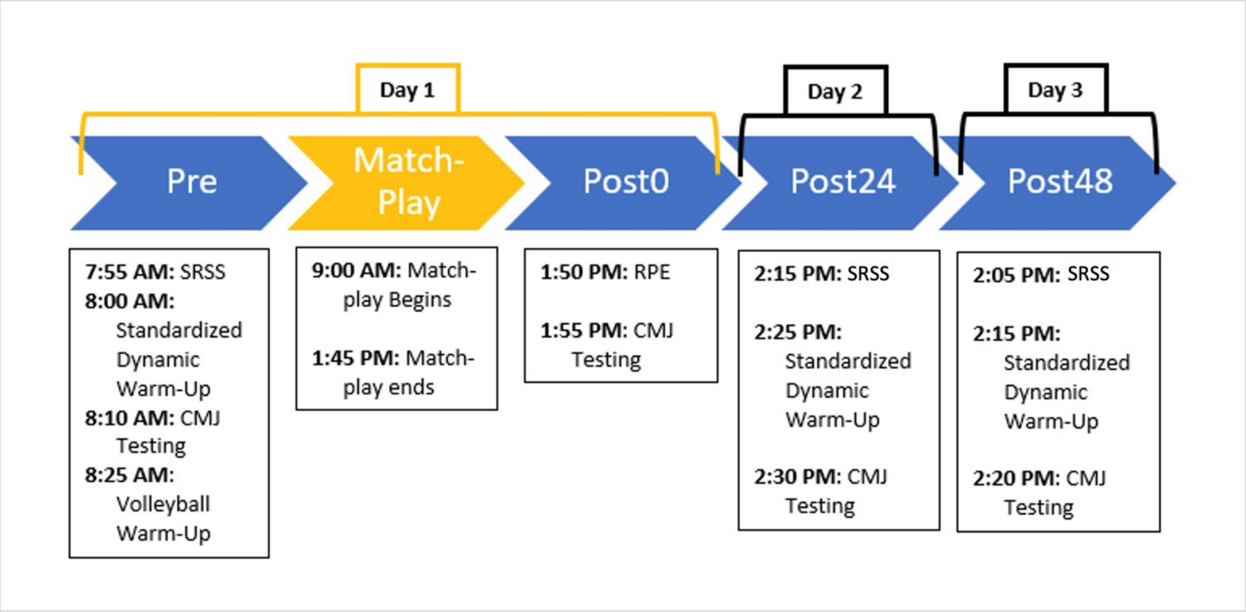
Post0. RPE was recorded independently by each athlete on paper within 10 minutes of conclusion of the final match. CMJ testing was completed in the same manner as before. CMJ initiated 10 minutes after completion of the final match.

Post24. SRSS, Standardized warm-up, and CMJ testing were completed again on the day following match play. The SRSS survey was completed between 24 and 24 hours 15 minutes of the previous day SRSS completion. The athletes then underwent the standardized-warm up. CMJ testing commenced 24 hours and 30 minutes after Post-0 jump testing commenced, 24 hours and 45 minutes after the completion of the final match.

Post48. SRSS, Standardized warm-up, and CMJ testing were completed again on the third day. The SRSS survey was completed between 48 hours and 48 hours 10 minutes of the previous day SRSS completion. The athletes then underwent the standardized-warm up. CMJ testing commenced 48 hours and 20 minutes after Post-0 jump testing commenced, 24 hours and 30 minutes after the completion of the final match.

Figure 3.1

Timeline of Tests.



Procedures

Short Recovery Stress Scale. The SRSS survey was used to subjectively measure player recovery and stress state each day. The survey consists of a recovery state assessment and a stress state assessment, each with 4 subscales, including physical performance capability (PPC), mental performance capability (MPC), emotional balance (EB), overall recovery (OR), muscular stress (MS), lack of activation (LA), negative emotional state (NES), and overall stress (OS) (Kölling et al., 2020). The survey was filled out independently by athletes on paper.

Standardized Dynamic Warm-Up. The participants completed a standardized dynamic warm-up before the Pre, Post24, and Post48 jump collection time-points. The warm-up consisted of light jogging, dynamic stretches, and bodyweight muscular activation exercises. The dynamic warm-up concluded with position specific jumps and agilities designed to mimic in-game activity.

CMJ Jump Testing. Each athlete completed the following procedures, one athlete at a time, immediately following the standardized dynamic warm-up. CMJ testing procedures were consistent at each time-point, including force plate placement (level, hard rubber horse stall mat atop concrete), athlete order, and clothing worn (shoes, knee pads, shorts, and jersey). The force plates were leveled before each testing session. CMJ testing began with each athlete completing a CMJ warm up trial at 75% perceived effort and another at maximum effort. All trials, including warmups, were completed on the force plates with a near weightless poly-vinyl chloride pipe resting on the back of their shoulders, held on their shoulders, just below the seventh cervical vertebrae. The force plates were then zeroed before each athlete completed their maximal trials for analysis. The athlete was directed to step onto the force plate and stand still for approximately three seconds to establish a static system weight. The athletes were allowed to jump on their own initiative after the three second quiet period, with the only instruction being "jump as high as you can." Two CMJ jump trials were recorded for analysis, separated by 60 seconds of rest. Athletes were required to give maximal effort and land on both force plates for the trial to be deemed valid. If these criteria were not met, the trial was dismissed, and an additional trial was completed for analysis. The results from the two trials were averaged together for analysis. Countermovement jump data was collected using dual force plates sampling at 1000Hz (ForceDecks FD Lite, Vald Performance, Brisbane, QLD). Data was collected and analyzed using the manufacturer's proprietary software (Force decks, Vald Performance, Newstead, QLS, AUS). Detection of movement initiation was set as 20 N from baseline weight. This value was calculated to be an average of 2.5% of the athletes' body mass, matching the recommendation by Meylan et al. (2011).

External Training Load. External training load was measured using seven portable microsensor units comprised of a gyroscope, magnetometer, and tri-axial accelerometer (Catapult OptimEye S5, Catapult Innovations, Team Sport 5.0, Melbourne, Australia) sampling at 100 hz. The units were secured to the subjects' upper backs between the scapulae via the manufacturer's custom-made harnesses. The accelerometry data was analyzed using the manufacturer's software (Catapult OpenField, Melbourne, Australia).

Session Rating of Perceived Exertion. Athlete RPE for the entire tournament was recorded independently by each athlete on paper using a modified Borg scale ranging from 0 = to 10 (Foster et al., 2001) within 10 minutes of conclusion of the final match (Uchida et al., 2014). Athletes were directed to rate their perceived exertion from all matches, not solely the final match. This rating was then multiplied by the total activity duration to calculate sRPE (Foster et al., 2001).

Statistical Analysis

The following CMJ variables were investigated: CMJH (derived from the impulse momentum relationship), PP, EccDur, ConDur, EccUnImp, EccDecImp, and CM Depth.

To assess changes in CMJ performance and SRSS results, a one-way repeated measure analysis of variance (ANOVA) was conducted. Significant main effect was followed by a Holm adjustment to further examine the result. Effect size using Hedge's g with a 95% CI was also calculated between time points for CMJ data. Effect size values were classified in the following manner: trivial ≤ 0.2, 0.2 < small ≤ 0.6, 0.6 < moderate ≤ 1.2, 1.2 < large ≤ 2.0, and < 2.0 = very large (Hopkins, 2000). The assumption of sphericity was evaluated using Mauchly's test. Violations of the assumption of sphericity were corrected using the Greenhouse-Geisser method. The assumption of normality was evaluated using a Shapiro-Wilke test. CMJ data found to be non-parametric was analyzed using Friedman's test with Conover's Post Hoc analysis. Due to the ordinal nature of Likert scales, SRSS results were also assessed via these non-parametric tests. The mean individual percent change in CMJ and SRSS results were quantified across timepoints. Pearson's coefficient correlation was performed to examine relationships between TL measurements and changes from baseline in CMJ kinetic variables that were found to change significantly. Correlation was classified in the following manner: r <0.10 = trivial, 0.10 ≤ r ≤ 0.30 = small, 0.30 ≤ r ≤ 0.50 = moderate, 0.5 ≤ r ≤ 0.7 = large, 0.70 ≤ r ≤ 0.90 = very large, 0.90 ≤ r ≤ 1.00 = nearly perfect, and r = 1.0 = perfect. All data were expressed as mean ± SD. Statistical significance was set at p = 0.05. Statistical analyses were performed in JASP (version 0.16.2) and Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA).

Results

ANOVA Assumptions

No violations of sphericity were revealed, as assessed by Maulchy's test, for any CMJ variables or SRSS results (p= 0.223 -0.865). No violations of normality for any CMJ variables were found, as assessed by Shapiro-Wilk tests (p=0.116-0.997).

Tournament Match Play

Three matches were played, two sets each match. 277 total points were played (46.2 ± 3.5 points per set). Athletes' match play duration averaged 110.9 ± 31.8 minutes total throughout the tournament (range: 38.95 - 129.33 min).

Training Loads from Match play

During the tournament, athletes accumulated a mean Player Load of 758.6 ± 216.89 au. Hitters (n=4) jumped 152.8 ± 81.9 times throughout tournament match play. The mean sRPE for the tournament was 1184.1 ± 363.2.

Short Recovery Stress Scale

Recovery. A statistically significant decrease in PPC was observed from Pre to Post24 (*p* = 0.043, -33%) (Table 3.1, Figure 3.1). Decrease in OR from Pre to Post 24 was observed approaching statistical significance (*p* = 0.067, -30%) (Figure 3.2). An increase in PPC was observed approaching significance from Post24 to Post48 (*p* = 0.069, 40%). Increase from Post24 to Post 48 in OR was observed, to a statistically insignificant extent (*p* = 0.136, 38.1%).

Stress. Statistically significant increases in SRSS stress items were observed from Pre to Post24: MS (*p* = 0.022, 136.4%), OS (*p* =0.043, 127.3%) (Table 3.1, Figure 3.4, Figure 3.5). NES increased substantially, although not to a statistically significant extent from Pre to Post24 (p=0.131, 266.7%) and Pre to Post 48 (p=0.131, 366.7%). Nonsignificant decreases in stress scales from Post24 to Post48 were observed: MS (*p* = 0.264, -23%), OS (*p* = 0.336, -24%).

Table 3.1

Changes in SRSS Responses Across Time-points

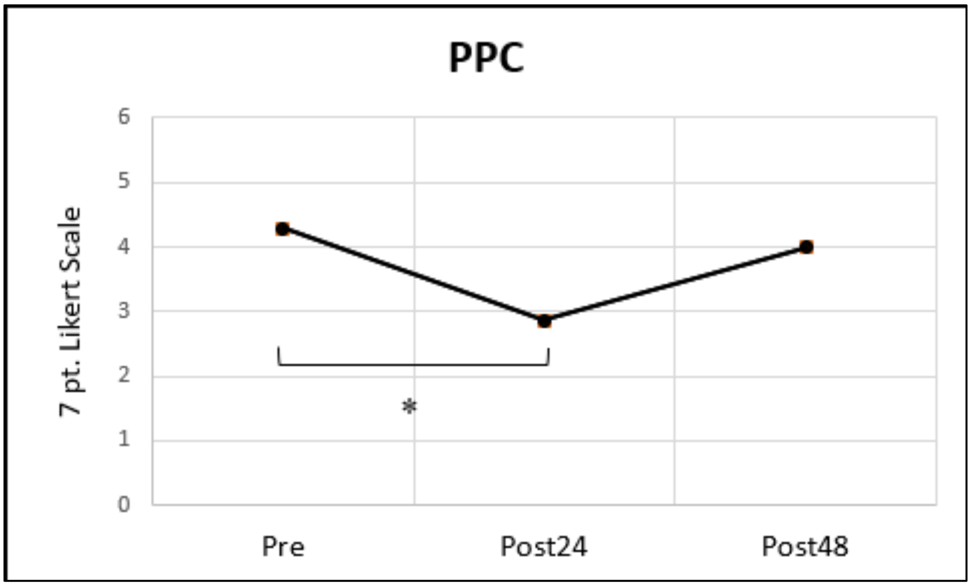
Item	**Pre**	**Post24**	**Post48**	**Percent Change (%)** **Pre-Post24**	**Pre-Post48**	**Post24-Post48**
			Recovery State			
PPC	4.3 ± 0.7	2.9 ± 0.6	4.0 ± 0.8	**-33.3 ***	-6.7	40.0
MPC	4.4 ± 0.7	3.3 ± 1.5	4.3 ± 1.0	-25.8	-3.2	30.4
EB	4.7 ± 0.7	4.4 ± 0.9	4.6 ± 1.2	-6.1	-3.0	3.2
OR	4.3 ± 0.9	3.0 ± 0.8	4.1 ± 1.1	-30.0	-3.3	38.1
			Stress State			
MS	1.6 ± 1.0	3.7 ± 1.3	2.9 ± 1.0	**136.4 ***	81.8	-23.1
LA	1.4 ± 0.7	3.3 ± 1.4	2.3 ± 1.5	130.0	60.0	-30.4
NES	0.4 ± 0.7	1.6 ± 1.2	2.0 ± 1.5	266.7	366.7	27.3
OS	1.6 ± 1.0	3.6 ± 1.4	2.7 ± 1.6	**127.3 ***	72.7	- 24.0

Pre, Post 24, Post48 columns represent average raw scores on a 7 point Likert scale (0-6). Positive % change values indicate an increase between time-points. PPC = physical performance capability, MPC = mental performance capability, EB = emotional balance, OR = overall recovery, MS = muscular stress, LA = lack of activation, NES = negative emotional state, and OS = overall stress.

* Denotes statistical significance ($p \leq 0.05$)

Figure 3.1

Physical Performance Capability (PPC) across all time-points



* Denotes statistical significance between time-points ($p \leq 0.05$).

Figure 3.2

Overall Recovery (OR) across all time-points

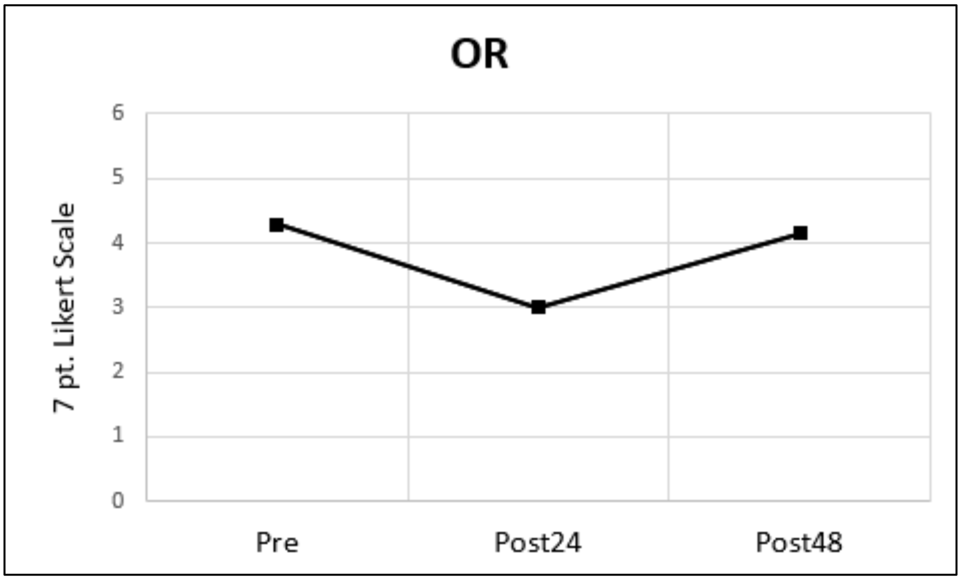
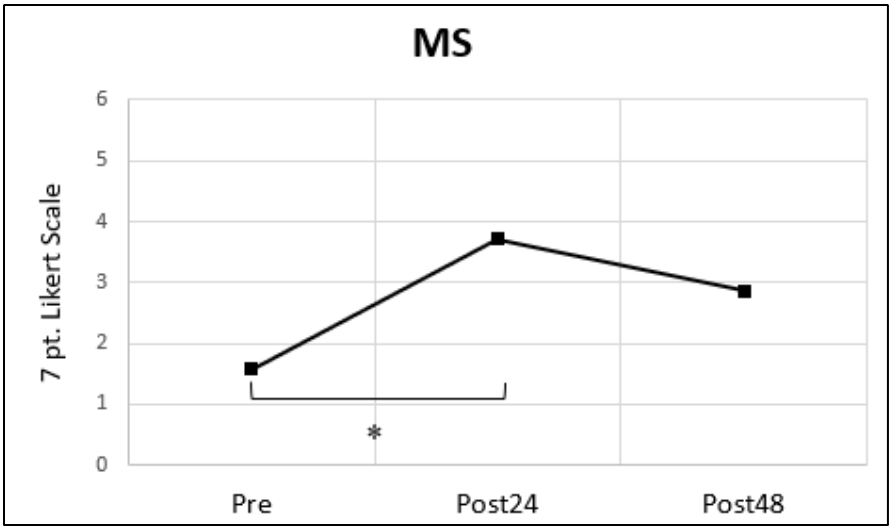


Figure 3.3

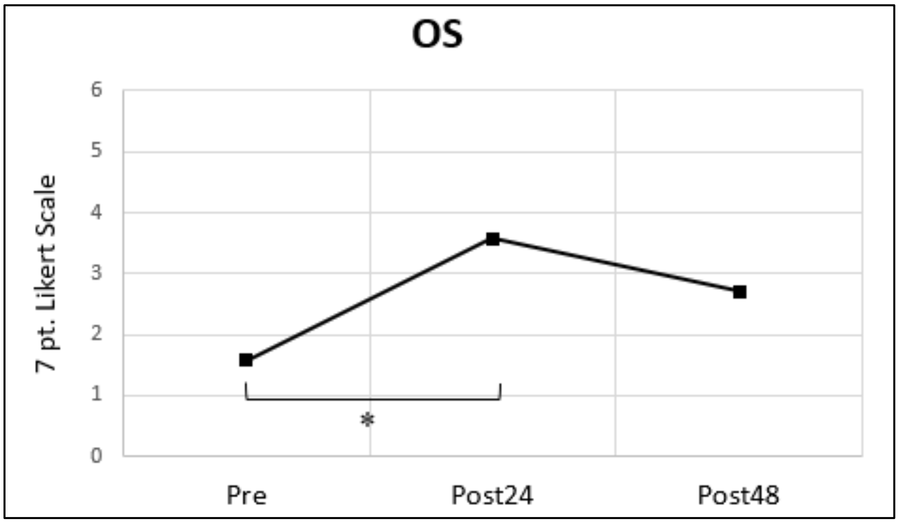
Muscular Stress (MS) across all time-points



* Denotes statistical significance ($p \leq 0.05$).

Figure 3.4

Overall Stress (OS) across all time-points



* Denotes statistical significance ($p \leq 0.05$).

Intrasession Reliability of Kinetic Variables

Test-retest reliability of the kinetic variables are displayed in Table 3.2. All variables revealed sufficient ICC (range, 0.88-0.99) and CV (range, 1.04 - 2.9%), except for CMDepth (ICC = 0.64, CV= 2.9 ± 1.6).

Table 3.2

Intrasession Reliability of Kinetic Variables

Variable	ICC	CV (%)
CMJH	0.99	1.6 ± 1.2
PP	0.93	1.0 ± 0.8
EccDur	0.92	1.9 ± 1.7
ConDur	0.88	2.4 ± 1.5
EccUnImp	0.95	2.9 ± 2.0
EccDecImp	0.95	3.0 ± 2.0
CMDepth	0.64	2.9 ± 1.6

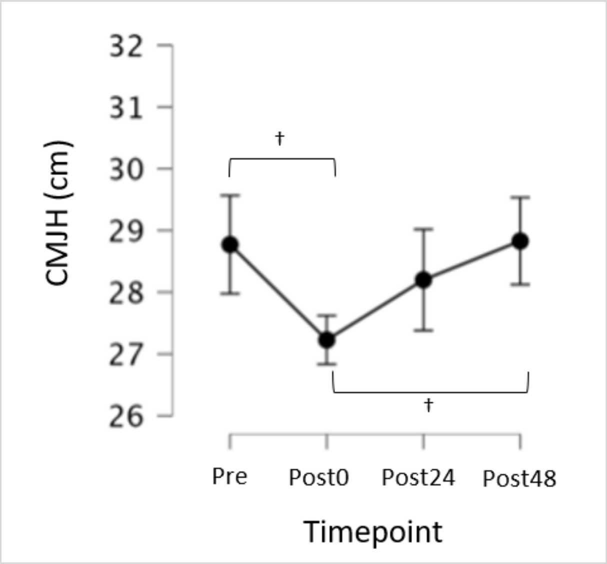
ICC = intraclass correlation, CV = coefficient of variation, CMJH = countermovement jump height, PP = peak power, EccDur = eccentric duration, ConDur = concentric duration, EccUnImp = eccentric unloading impulse, EccDecImp = eccentric deceleration impulse, CMDepth= countermovement depth

Maximal Jump Performance

A statistically significant small decrease in CMJH was observed between Pre and Post0 ($p = 0.006$, $g = - 0.216$) (Figure 3.2). CMJH increased non-significantly from Post0 to Post24 ($p = 0.109$, $g = 0.130$). A statistically significant small increase in CMJH was observed from Post0 to Post48 ($p = 0.006$, $g = 0.216$). No other statistically significant changes were observed in any variables (Table 3.2).

Figure 3.5

Countermovement Jump Height (CMJH) across all time-points



† Denotes statistical significance between time-points ($p \leq 0.01$). Error bars represent 95% confidence interval.

Table 3.3

Changes in Kinetic Variables Across Time-points

					Percent Change (%)		
Variable	**Pre**	**Post0**	**Post24**	**Post48**	**Pre-Post0**	**Pre-Post24**	**Pre-Post48**
BW [kg]	81.7 ± 16.6	82.0 ± 16.67	81.5 ± 16.2	81.3 ± 16.4	0.4	-0.2	-0.5
CMDepth [cm]	-36.0 ± 1.7	-36.0 ± 3.0	-35.7 ± 2.3	-37.0 ± 2.6	-0.2	-0.9	2.7
CMJH [cm]	28.8 ± 6.0	27.2 ± 6.4	28.2 ± 6.6	28.8 ± 6.4	**-5.4†**	-2.0	0.2
PP [W]	3414.3 ± 222.8	3347.1 ± 187.3	3375.4 ± 231.1	3390.9 ± 225.3	-2.0	-1.1	-0.7
ConDur [ms]	326.4 ± 40.5	327.9 ± 36.9	332.7 ± 36.7	333.1 ± 29.5	0.4	1.9	2.1
EccDur [ms]	548.9 ± 81.9	534.1 ± 77.4	551.6 ± 74.0	544.6 ± 43.8	-2.7	0.5	-0.8
EccUnImp [Ns]	-103.2 ± 21.6	-102.7 ± 19.8	-100.6 ± 23.0	-106.5 ± 20.8	-0.5	-2.5	3.2
EccDecImp [Ns]	103.3 ± 21.6	102.5 ± 19.9	100.7 ± 23.1	106.6 ± 20.9	-0.7	-2.5	3.2

Note. Positive values indicate an increase between timepoints. BW = body weight, CMJH = countermovement jump height, PP = peak power, EccDur = eccentric duration, ConDur = concentric duration, EccUnImp = eccentric unloading impulse, EccDecImp = eccentric deceleration impulse, CMDepth= countermovement depth

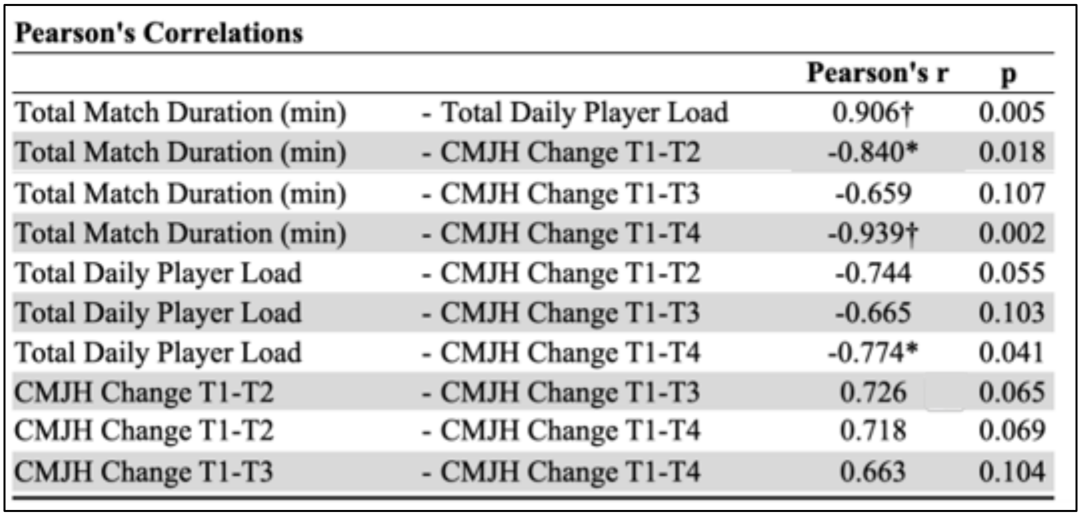
† Denotes statistical significance ($p \leq 0.01$).

Relationship of External Training Loads with Changes in Countermovement Jump

A statistically significant, nearly perfect correlation was observed between total match play duration and total daily PL ($r = 0.906$) (Table 3.4). Total match play duration showed very statistically significant large and nearly perfect correlations with changes in CMJH from Pre-Post0 and Pre-Post48, respectively. Several moderate to large correlations were found between total PL and changes in CMJH, but only the relationship between PL and CMJH change Pre-Post48 was statistically significant.

Table 3.4

Pearson's Correlations of External Training Load's relationship to CMJH



Pearson's Correlations

		Pearson's r	p
Total Match Duration (min)	- Total Daily Player Load	0.906†	0.005
Total Match Duration (min)	- CMJH Change T1-T2	-0.840*	0.018
Total Match Duration (min)	- CMJH Change T1-T3	-0.659	0.107
Total Match Duration (min)	- CMJH Change T1-T4	-0.939†	0.002
Total Daily Player Load	- CMJH Change T1-T2	-0.744	0.055
Total Daily Player Load	- CMJH Change T1-T3	-0.665	0.103
Total Daily Player Load	- CMJH Change T1-T4	-0.774*	0.041
CMJH Change T1-T2	- CMJH Change T1-T3	0.726	0.065
CMJH Change T1-T2	- CMJH Change T1-T4	0.718	0.069
CMJH Change T1-T3	- CMJH Change T1-T4	0.663	0.104

* Denotes statistical significance ($p \leq 0.05$)

† Denotes statistical significance ($p \leq 0.01$).

Discussion

Match play duration results yielded sufficient playing time for all participants to be included in analysis. Collegiate court WVB is typically played in a best of 5 sets manner, with 3 set matches being significantly shorter and less stressful than 5 set matches (Vlantes & Readdy, 2017). The unique tournament design was different than that of typical match-play, therefore, activity was quantified in order to obtain a more precise measure of training load in the current study. Results were compared to that of Vlantes & Readdy (2017), who observed training loads in Division 1 (D1) WVB match play throughout a competitive season using the same make and model of microsensor.

VJ volume was assessed via automatic jump detection from the Catapult microsensor, a previously validated method of quantifying jump volume in similar devices (Charlton et al., 2017; Gageler, Wearing, & James, 2015). Outside hitters (OH) and middle blockers (MB) observed in the current study (n=4) completed a similar quantity of jumps as reported in 5 set matches (OH: 82 ± 31.2 jumps, MB: 171 ± 33.4 jumps) (Vlantes & Readdy, 2017). These results are slightly greater than those reported by Tillman et al. (2004), who only reported an average 45 jumps between two sets, equating to approximately 112 jumps per 5 sets.

Previous literature has suggested that VJ volume alone may not be sufficient to assess external load (Pelzer et al., 2020, Sanders et al., 2018). This is likely due to the variety of high intensity movements volleyball athletes perform (Pelzer et al., 2020; Sheppard et al., 2008). Therefore, metrics such as PL may be useful, as it summates activity in all axes (Vlantes & Readdy, 2017). The device used in the current study to measure PL had been previously shown to be sufficiently reliable in laboratory and sport settings (Boyd, Ball & Aughey, 2011). The current study observed substantially higher total PL than the previous reported average of 484 ± 125.7 au in 5 set matches (Vlantes & Readdy, 2017).

Internal training load in the current study was assessed via sRPE. This method has been previously validated in high-level volleyball (Rodríguez-Marroyo et al., 2014). sRPE observed in the current study was similar to that reported by Vlantes & Readdy (2017) in 5 set matches (1038 ± 294.9 au.). Pelzer et al. (2020) reported substantially lower sRPE from 3 different practice session types (439 ± 208 to 689 ± 158 au).

Due to the unique tournament design, it is difficult to precisely compare the total amount of match play to a single, normal match. This is a limitation of the present study. Based on the jump quantity, PL, & sRPE, the match observed in the current study likely equates to at least that of a 5-set match. Previous literature observing changes in maximal VJ performance was likely underpowered to replicate volleyball match play workloads, and therefore elicit fatigue (Brazo-Sayavera et al., 2017, Pelzer et al. 2020). This likely explains the divergent results of the current study and the previous literature. If acute decrements in VJ as a result of volleyball match are possible, the training load experienced in the current study is sufficiently powered to reveal such results. Future researchers should however be cognizant of the high levels of external load in the current study when attempting to extrapolate the results to lesser matches or training sessions.

The SRSS is a valid method of monitoring athletes' perceived wellbeing and readiness status in English speaking countries (Kölling et al., 2020). Results of the SRSS in the present study are displayed in Table 3.1. The SRSS results suggest that, compared to baseline, the athletes' perceived recovery may be decreased (Figure 3.1, Figure 3.2) and perceived stress may be increased (Figure 3.3, Figure 3.4) at 24 hours post-match. This response is logical based on the training load completed during the tournament. The results further indicate that while perceived recovery likely will return to baseline levels by 48 hours post-match, the athletes may retain increased perceived stress increased stress 48 hours post-match, with a trend towards a return to baseline values. While these results can be useful to help explain the time course of perceived recovery from match play, the change in physical performance characteristics should additionally be considered as these measures represent the athlete's actual physical capabilities.

Acceptable intrasession reliability was observed in all, except for CMDepth (Table 3.2). While the ICC for CMDepth yielded lower reliability than what was observed for other variables, the low CV (>3%) yielded sufficient reliability to be included in analysis.

The only CMJ kinetic variable to display statistically significant change at any time-point was CMJH (Table 3.3, Figure 3.5). These results suggest that maximal jump performance may be inhibited immediately after match play, and will return to baseline by 48 hours post-match, but not necessarily by 24 hours post-match.

These results are in line with the current understanding of fatiguing NM interventions (Boyas & Guével, 2011; Claudino et al., 2017; Gathercole et al., 2015; Kamandulis et al., 2016; Rodacki et al., 2002; Skurvydas et al., 2002, Watkins et al., 2017). They are, however, contrary to the acute monitoring research in volleyball. Brazo-Sayavera et al. (2017) monitored changes in maximal jump performance in high-level WVB athletes after a volleyball training intervention. As previously discussed, the intervention by Brazo-Sayavera and colleagues (2017) did not represent the training loads associated with match play. This likely explains the lack of changes in jump performance post intervention. The current study contained considerably higher workloads, which can account for the observed changes in CMJH. Pelzer et al. (2020) observed changes in physical performance and indirect markers of fatigue and muscle damage after different practices in elite youth men and women beach volleyball athletes. Despite observing increases in creatine kinase and delayed onset muscle soreness, VJ ability increased slightly post intervention, although to a statistically non-significant extent (Pelzer et al., 2020). The authors noted the difficulty of extrapolating results from sand volleyball to court volleyball (Pelzer et al., 2020). Pelzer et al. (2020) reported significantly lower sRPE than the sRPE observed in the current study and previously reported match play values (Vlantes & Readdy, 2017). Gender, playing surface, and/or lower training loads therefore could explain the contradictory outcomes between the current study and the results reported by Pelzer et al. (2020). These differentiating factors may also explain the divergent results of the current study and those reported by Magalhães et al. (2011). Magalhães et al. (2011) reported no change in VJ height post-match play in elite men beach volleyball athletes, despite significant decreases in maximal voluntary contraction of the leg musculature and decreased sprint performance. The acute volleyball monitoring studies included several methodological flaws contrasting the recommendations by Claudino et al., (2017), who concluded that CMJ trials with no arm swing should be averaged in order to accurately assess NM status. This could additionally explain the lack of changes in maximal VJ performance in the previous acute volleyball research.

Previous research has indicated that jump mechanics may change during fatigued conditions, such as altered CMDepth (Carroll et al., 2019; Rodacki et al., 2002). Gathercole et al. (2015) additionally suggested changes in kinetic variables such as EccDur and ConDur may represent changes in jump strategy when fatigued. However, the current study revealed no changes in any variables that might suggest changes in jump strategy (CMDepth, EccDur, ConDur, EccUnImp, EccDecImp). These findings suggest that changes in jump movement strategy may not be expected after match play in the studied population.

PP has also been identified as a variable that may be appropriate for monitoring acute changes in NM status (Carroll et al., 2019; Gathercole et al., 2015; Ishida et al., 2021; Sams, 2014). However, the relatively small change in PP in the current study does not support the previous suggestions. These differences may be due to study design factors including sport and testing time-points.

The results from the current study suggest that match play duration may have a stronger relation to changes in CMJH than PL (Table 3.4). It is logical to predict that greater match play duration and PL would indicate greater decrements to NM status, and therefore maximal jump performance. While the results from the current study may lean towards supporting this prediction, the analysis may however be limited to the small sample size of the current study (n=7). Further research with larger samples should be conducted to more assuredly assess the relationship between external load and changes in maximal jump performance in collegiate WVB.

Practical Applications

The current study indicates that maximal jump performance can be negatively affected by collegiate WVB match play. CMJH is likely to decrease immediately after match play and may not make a full return to baseline until 48 hours post-match. NM status is likely recovered by 48 hours post-match despite lingering perceived muscular and overall stress. This suggests that match play or training sessions occurring 24 hours post-match play could be somewhat compromised by insufficient recovery. These results may, however, be dependent upon several factors, including the external training load associated with match play. Further studies should be conducted with larger sample sizes and multiple match play assessments to expound on these results.

Testing CMJH is likely a useful acute assessment of NM status in collegiate WVB. The data collection methods from the acute monitoring strategy in the current study can be used by coaches seeking to inform the training process. Practitioners can use methods similar to those outlined in the current study to acutely monitor collegiate WVB athletes.

References

Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, *21*(4), 1192–1196.

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

Boyas, S., & Guével, A. (2011). Neuromuscular fatigue in healthy muscle: Underlying factors and adaptation mechanisms. *Annals of Physical and Rehabilitation Medicine*, *54*(2), 88–108. https://doi.org/10.1016/j.rehab.2011.01.001

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *International Journal of Sports Physiology and Performance*, 6(3), 311–321. https://doi.org/10.1123/ijspp.6.3.311

Brazo-Sayavera, J., Nikolaidis, P., Camacho-Cardenosa, A., Camacho-Cardenosa, M., Timón, R., & Olivares, P. (2017). Acute effects of block jumps in female volleyball players: The role of performance level. *Sports*, *5*(2), 30. https://doi.org/10.3390/sports5020030

Carroll, K. M., Wagle, J. P., Sole, C. J., & Stone, M. H. (2019). Intrasession and Intersession Reliability of Countermovement Jump Testing in Division-I Volleyball Athletes. *Journal of Strength and Conditioning Research*, *33*(11), 2932–2935. https://doi.org/10.1519/JSC.0000000000003353

Charlton, P., Kenneally-Dabrowski, C., Sheppard, J., & Spratford, W. (2017). A simple method for quantifying jump loads in volleyball athletes. *Journal of Science and Medicine in Sport*, 20 3, 241-245 .

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

Duarte, T. S., Alves, D. L., Coimbra, D. R., Miloski, B., Bouzas Marins, J. C., & Bara Filho, M. G. (2019). Technical and tactical training load in professional volleyball players. *International Journal of Sports Physiology and Performance*, *14*(10), 1338–1343. https://doi.org/10.1123/ijspp.2019-0004

Edwards R. H. (1981). Human muscle function and fatigue. *Ciba Foundation Symposium*, 82, 1–18. https://doi.org/10.1002/9780470715420.ch1

Fleck, S. J., Case, S., Puhl, J., & Van Handle, P. (1985). Physical and physiological characteristics of elite women volleyball players. *Canadian Journal of Applied Sport Sciences. Journal Canadien Des Sciences Appliquees Au Sport*, *10*(3), 122–126.

Foster, C., Florhaug., Franklin, J., Gottschall, L., Hrovatin, L., Parker, S., Doleshal, P., Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research: National Strength & Conditioning Association*. *15*. 109-15. 10.1519/00124278-200102000-00019.

Fry, A. C., Kraemer, W. J., Weseman, C. A., Conroy, B. P., Gordon, S. E., Hoffman, J. R., & Maresh, C. M. (1991). The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *The Journal of Strength and Conditioning Research*, *5*(4), 174. https://doi.org/10.1519/1533-4287(1991)005<0174:TEOAOS>2.3.CO;2

Gabbett, T., & Georgieff, B. (2007). Physiological and Anthropometric Characteristics of Australian Junior National, State, and Novice Volleyball Players. *The Journal of Strength and Conditioning Research*, *21*(3), 902. https://doi.org/10.1519/R-20616.1

Gageler, H., Wearing, S., & James, A. (2015). Automatic jump detection method for athlete monitoring and performance in volleyball. *International Journal of Performance Analysis in Sport*, *15*, 284 – 296.

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). 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

Gladden, L. B., & Colacino, D. (1974). Characteristics of volleyball players and success in a national tournament. *Journal of Sports Medicine and Physical Fitness*, *18*(1), 57–64.

Hopkins, W. G. (2000). A new view of statistics. Internet Society for Sport Science: http://www.sportsci.org/resource/stats/.

Hopkinson, M, Smolianov, P, Dion, S, and Schoen, C (2016). Identifying best practices for advancement of US volleyball. *West East Institute International Academic Conference on Business and Economics* Harvard University. Boston, MA, 2016

Ishida, A., Bazyler, C. D., Sayers, A. L., Mizuguchi, S., & Gentles, J. A. (2021). acute effects of match play on neuromuscular and subjective recovery and stress state in division in collegiate female soccer players. *Journal of Strength and Conditioning Research*, *35*(4), 976–982. https://doi.org/10.1519/JSC.0000000000003981

Kamandulis, S., Venckunas, T., Snieckus, A., Nickus, E., Stanislovaitiene, J., & Skurvydas, A. (2016). Changes of vertical jump height in response to acute and repetitive fatiguing conditions. *Science & Sports*, *31*(6), e163–e171. https://doi.org/10.1016/j.scispo.2015.11.004

Kölling, S., Schaffran, P., Bibbey, A., Drew, M., Raysmith, B., Nässi, A., & Kellmann, M. (2020). Validation of the Acute Recovery and Stress Scale (ARSS) and the Short Recovery and Stress Scale (SRSS) in three English-speaking regions. *Journal of sports sciences, 38(2),* 130–139. https://doi.org/10.1080/02640414.2019.1684790

Künstlinger, U., Ludwig, H. G., & Stegemann, J. (1987). Metabolic changes during volleyball matches. *International Journal of Sports Medicine*, *08*(5), 315–322. https://doi.org/10.1055/s-2008-1025676

Lidor, R., & Ziv, G. (2010). Physical and Physiological Attributes of Female Volleyball Players-A review. *Journal of Strength and Conditioning Research*, *24*(7), 1963–1973. https://doi.org/10.1519/JSC.0b013e3181ddf835

Linnamo, V., Häkkinen, K., & Komi, P. V. (1997). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology and Occupational Physiology*, *77*(1), 176–181.

Magalhães, J., Inácio, M., Oliveira, E., Ribeiro, J. C., & Ascensão, A. (2011). Physiological and neuromuscular impact of beach-volleyball with reference to fatigue and recovery. *The Journal of Sports Medicine and Physical Fitness*, *51*(1), 66–73.

Meylan, C., Nosaka, K., Green, J., & Cronin, J. (2011). The effect of three different start thresholds on the kinematics and kinetics of a countermovement jump. *Journal of Strength and Conditioning Research*, 25(4), 1164–1167. https://doi.org/10.1519/JSC.0b013e3181c699b9

Pascal, J. R. (2020). *The Impact of a Division I Volleyball Season on Jumping Performance*. Georgia Southern University.

Pelzer, T., Schmidt, M., Jaitner, T., & Pfeiffer, M. (2020). External training load and the effects on training response following three different training sessions in young elite beach volleyball players. *International Journal of Sports Science & Coaching*, *15*(5–6), 717–727. https://doi.org/10.1177/1747954120940488

Plisk, S. S., & Stone, M. H. (2013). Periodization Strategies. *Strength and Conditioning Journal*: *National Strength and Conditioning Association*. *25*(6), 19-37.

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: Fatigue effects: *Medicine & Science in Sports & Exercise*, *34*(1), 105–116. https://doi.org/10.1097/00005768-200201000-00017

Rodríguez-Marroyo, J.A., Medina, J., García-López, J., García-Tormo, J.V., & Foster, C.C. (2014). Correspondence Between Training Load Executed by Volleyball Players and the One Observed by Coaches. *Journal of Strength and Conditioning Research, 28*, 1588–1594.

Sams, ML., (2014). Comparison of static and countermovement jump variables in relation to estimated training load and subjective measures of fatigue. Electronic Theses and Dissertations. Paper 2411. https://dc.etsu.edu/etd/2411

Sanders, G. J., Boos, B., Shipley, F., & Scheadler, C. M. (2018). An accelerometer-based training load analysis to assess volleyball performance. *Journal of Exercise and Nutrition Open Access*, *1*(1), 5. https://www.journalofexerciseandnutrition.com/index.php/JEN/article/view/4

Sheppard, J. M., Cronin, J. B., Gabbett, T. J., McGuigan, M. R., Etxebarria, N., & Newton, R. U. (2008). relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *Journal of Strength and Conditioning Research*, *22*(3), 758–765. https://doi.org/10.1519/JSC.0b013e31816a8440

Skurvydas, A., Dudoniene, V., Kalvėnas, A., & Zuoza, A. (2002). Skeletal muscle fatigue in long-distance runners, sprinters and untrained men after repeated drop jumps performed at maximal intensity. *Scandinavian Journal of Medicine & Science in Sports*, *12*(1), 34–39. https://doi.org/10.1034/j.1600-0838.2002.120107.x

Smith, D. J., Roberts, D., & Watson, B. (1992). Physical, physiological and performance differences between Canadian national team and Universiade volleyball players. *Journal of Sports Sciences*, *10*(2), 131–138. https://doi.org/10.1080/02640419208729915

Spence, D. W., Disch, J. G., Fred, H. L., & Coleman, A. E. (1980). Descriptive profiles of highly skilled women volleyball players: *Medicine & Science in Sports & Exercise*, *12*(4), 299-302. https://doi.org/10.1249/00005768-198024000-00013

Strojnik, V., & Komi, P. V. (1998). Neuromuscular fatigue after maximal stretch-shortening cycle exercise. *Journal of Applied Physiology*, *84*(1), 344–350. https://doi.org/10.1152/jappl.1998.84.1.344

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. *Journal of Australian Strength & Conditioning, 20*(1), 13.

Tillman, M. D., Hass, C. J., Brunt, D., & Bennett, G. R. (2004). Jumping and Landing Techniques in Elite Women's Volleyball. *Journal of Sports Science & Medicine*, *3*(1), 30–36.

Uchida, M. C., Teixeira, L. F., Godoi, V. J., Marchetti, P. H., Conte, M., Coutts, A. J., & Bacurau, R. F. (2014). Does the timing of measurement alter Session-RPE in boxers? *Journal of Sports Science & Medicine*, *13*(1), 59–65.

Vlantes, T. G., & Readdy, T. (2017). Using microsensor technology to quantify match demands in collegiate women's volleyball. *Journal of Strength and Conditioning Research*, *31*(12), 3266–3278. https://doi.org/10.1519/jsc.0000000000002208

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

Chapter 4. Conclusion

The purpose of the present thesis was to fill the current gap in literature by investigating the acute changes in NM status and maximal jump performance after match play in collegiate women's volleyball. Additionally, the study was designed to establish an acute athlete monitoring system effective in assessing the NM status of collegiate women's volleyball athletes.

The current study indicates that maximal jump performance can be negatively affected by collegiate WVB match play. CMJH is likely to decrease immediately after match play and may not make a full return to baseline until 48 hours post-match. NM status is likely recovered by 48 hours post-match despite lingering perceived muscular and overall stress. No indications of altered movement strategy were observed. These results may, however, be dependent upon several factors, including the external training load associated with match play. Further studies should be conducted with larger sample sizes to expound on these results.

Practically, testing CMJH is a useful acute assessment of NM status in collegiate WVB. The real-time data collected from this acute monitoring strategy can be utilized by coaches seeking to inform the training process. Practitioners can use methods similar to those outlined in the current study to acutely monitor collegiate WVB athletes.

References

Allen, D. G., Westerblad, H., Lee, J. A., & Lännergren, J. (1992). Role of excitation-contraction coupling in muscle fatigue. *Sports Medicine*, *13*(2), 116–126. https://doi.org/10.2165/00007256-199213020-00007

Barnes, J. L., Schilling, B. K., Falvo, M. J., Weiss, L. W., Creasy, A. K., & Fry, A. C. (2007). Relationship of jumping and agility performance in female volleyball athletes. *Journal of Strength and Conditioning Research*, *21*(4), 1192–1196.

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

Bobbert, M. F., & Van Soest, A. J. (1994). Effects of muscle strengthening on vertical jump height: A simulation study. *Medicine and Science in Sports and Exercise*, 26(8), 1012-1020. https://doi.org/10.1249/00005768-199408000-00013

Boyas, S., & Guével, A. (2011). Neuromuscular fatigue in healthy muscle: Underlying factors and adaptation mechanisms. *Annals of Physical and Rehabilitation Medicine*, *54*(2), 88–108. https://doi.org/10.1016/j.rehab.2011.01.001

Boyd, L. J., Ball, K., & Aughey, R. J. (2011). The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. *International Journal of Sports Physiology and Performance*, 6(3), 311–321. https://doi.org/10.1123/ijspp.6.3.311

Brazo-Sayavera, J., Nikolaidis, P., Camacho-Cardenosa, A., Camacho-Cardenosa, M., Timón, R., & Olivares, P. (2017). Acute effects of block jumps in female volleyball players: The role of performance level. *Sports*, *5*(2), 30. https://doi.org/10.3390/sports5020030

Carroll, K. M., Wagle, J. P., Sole, C. J., & Stone, M. H. (2019). Intrasession and Intersession Reliability of Countermovement Jump Testing in Division-I Volleyball Athletes. *Journal of Strength and Conditioning Research*, *33*(11), 2932–2935. https://doi.org/10.1519/JSC.0000000000003353

Charlton, P., Kenneally-Dabrowski, C., Sheppard, J., & Spratford, W. (2017). A simple method for quantifying jump loads in volleyball athletes. *Journal of Science and Medicine in Sport*, 20 3, 241-245 .

Chiu, L. Z. F., & Barnes, J. L. (2003). The fitness-fatigue model revisited: Implications for planning short and long-term training. *Strength and Conditioning Journal*, *25*(6), 42. https://doi.org/10.1519/1533-4295(2003)025<0042:TFMRIF>2.0.CO;2

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

Cunanan, A. J., DeWeese, B. H., Wagle, J. P., Carroll, K. M., Sausaman, R., Hornsby, W. G., Haff, G. G., Triplett, N. T., Pierce, K. C., & Stone, M. H. (2018). The General Adaptation Syndrome: A Foundation for the Concept of Periodization. *Sports Medicine*, *48*(4), 787–797. https://doi.org/10.1007/s40279-017-0855-3

Dalsgaard, M. K., Ide, K., Cai, Y., Quistorff, B., & Secher, N. H. (2002). The intent to exercise influences the cerebral O2/carbohydrate uptake ratio in humans. *The Journal of Physiology*, *540*(Pt 2), 681–689. https://doi.org/10.1113/jphysiol.2001.013062

Davis, J. M., & Bailey, S. P. (1997). Possible mechanisms of central nervous system fatigue during exercise. *Medicine & Science in Sports & Exercise*, *29*(1), 45–57.

DeWeese, B. H., Hornsby, G., Stone, M., & Stone, M. H. (2015). The training process: Planning for strength–power training in track and field. Part 1: Theoretical aspects. *Journal of Sport and Health Science*, *4*(4), 308–317. https://doi.org/10.1016/j.jshs.2015.07.003

Descartes, R. (1983). Principles of Philosophy (1644), trans., V. R. Miller and R. P. Miller. Dordrecht: Kluwer Academic Publishers.

Duarte, T. S., Alves, D. L., Coimbra, D. R., Miloski, B., Bouzas Marins, J. C., & Bara Filho, M. G. (2019). Technical and tactical training load in professional volleyball players. *International Journal of Sports Physiology and Performance*, *14*(10), 1338–1343. https://doi.org/10.1123/ijspp.2019-0004

Edwards R. H. (1981). Human muscle function and fatigue. *Ciba Foundation Symposium*, 82, 1–18. https://doi.org/10.1002/9780470715420.ch1

Fleck, S. J., Case, S., Puhl, J., & Van Handle, P. (1985). Physical and physiological characteristics of elite women volleyball players. *Canadian Journal of Applied Sport Sciences. Journal Canadien Des Sciences Appliquees Au Sport*, *10*(3), 122–126.

Foster, C. (1998). Monitoring training in athletes with reference to overtraining syndrome. *Medicine & Science in Sports & Exercise*, *30*(7), 1164–1168. https://doi.org/10.1097/00005768-199807000-00023

Foster, C., Florhaug., Franklin, J., Gottschall, L., Hrovatin, L., Parker, S., Doleshal, P., Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research: National Strength & Conditioning Association*. *15*. 109-15. 10.1519/00124278-200102000-00019.

Fry, A. C., Kraemer, W. J., Weseman, C. A., Conroy, B. P., Gordon, S. E., Hoffman, J. R., & Maresh, C. M. (1991). The effects of an off-season strength and conditioning program on starters and non-starters in women's intercollegiate volleyball. *The Journal of Strength and Conditioning Research*, *5*(4), 174. https://doi.org/10.1519/1533-4287(1991)005<0174:TEOAOS>2.3.CO;2

Gabbett, T., & Georgieff, B. (2007). Physiological and Anthropometric Characteristics of Australian Junior National, State, and Novice Volleyball Players. *The Journal of Strength and Conditioning Research*, *21*(3), 902. https://doi.org/10.1519/R-20616.1

Gageler, H., Wearing, S., & James, A. (2015). Automatic jump detection method for athlete monitoring and performance in volleyball. *International Journal of Performance Analysis in Sport*, *15*, 284 – 296.

Gathercole, R. J., Sporer, B. C., Stellingwerff, T., & Sleivert, G. G. (2015). 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

Gladden, L. B., & Colacino, D. (1974). Characteristics of volleyball players and success in a national tournament. *Journal of Sports Medicine and Physical Fitness*, *18*(1), 57–64.

Haff, G., & Triplett, N. T. (2021). *Essentials of strength training and conditioning* (4th ed.). Human Kinetics.

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

Hopkins, W. G. (2000). A new view of statistics. Internet Society for Sport Science: http://www.sportsci.org/resource/stats/.

Hopkinson, M, Smolianov, P, Dion, S, and Schoen, C (2016). Identifying best practices for advancement of US volleyball. *West East Institute International Academic Conference on Business and Economics* Harvard University. Boston, MA, 2016

Ishida, A., Bazyler, C. D., Sayers, A. L., Mizuguchi, S., & Gentles, J. A. (2021). acute effects of match play on neuromuscular and subjective recovery and stress state in division in collegiate female soccer players. *Journal of Strength and Conditioning Research*, *35*(4), 976–982. https://doi.org/10.1519/JSC.0000000000003981

Kamandulis, S., Venckunas, T., Snieckus, A., Nickus, E., Stanislovaitiene, J., & Skurvydas, A. (2016). Changes of vertical jump height in response to acute and repetitive fatiguing conditions. *Science & Sports*, *31*(6), e163–e171. https://doi.org/10.1016/j.scispo.2015.11.004

Kölling, S., Schaffran, P., Bibbey, A., Drew, M., Raysmith, B., Nässi, A., & Kellmann, M. (2020). Validation of the Acute Recovery and Stress Scale (ARSS) and the Short

Recovery and Stress Scale (SRSS) in three English-speaking regions. *Journal of sports sciences, 38(2),* 130–139. https://doi.org/10.1080/02640414.2019.1684790

Künstlinger, U., Ludwig, H. G., & Stegemann, J. (1987). Metabolic changes during volleyball matches. *International Journal of Sports Medicine*, *08*(5), 315–322. https://doi.org/10.1055/s-2008-1025676

Lagier-Tessonnier, F., Balzamo, E., & Jammes, Y. (1993). Comparative effects of ischemia and acute hypoxemia on muscle afferents from tibialis anterior in cats. *Muscle & Nerve*, *16*(2), 135–141. https://doi.org/10.1002/mus.880160203

Lauritzen, F., Paulsen, G., Raastad, T., Bergersen, L. H., & Owe, S. G. (2009). Gross ultrastructural changes and necrotic fiber segments in elbow flexor muscles after maximal voluntary eccentric action in humans. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *107*(6), 1923–1934. https://doi.org/10.1152/japplphysiol.00148.2009

Lidor, R., & Ziv, G. (2010). Physical and Physiological Attributes of Female Volleyball Players-A review. *Journal of Strength and Conditioning Research*, *24*(7), 1963–1973. https://doi.org/10.1519/JSC.0b013e3181ddf835

Linnamo, V., Häkkinen, K., & Komi, P. V. (1997). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology and Occupational Physiology*, *77*(1), 176–181.

Magalhães, J., Inácio, M., Oliveira, E., Ribeiro, J. C., & Ascensão, A. (2011). Physiological and neuromuscular impact of beach-volleyball with reference to fatigue and recovery. *The Journal of Sports Medicine and Physical Fitness*, *51*(1), 66–73.

Magleby, K. L., & Pallotta, B. S. (1981). A study of desensitization of acetylcholine receptors using nerve-released transmitter in the frog. *The Journal of Physiology*, *316*, 225–250.

McGinnis, P. M. (2013). *Biomechanics of Sport and Exercise* (Third edition). Human Kinetics.

McMahon, J. J., Suchomel, T. J., Lake, J. P., & Comfort, P. (2018). Understanding the key phases of the countermovement jump force-time curve. *Strength & Conditioning Journal*, *40*(4), 96–106. https://doi.org/10.1519/SSC.0000000000000375

Meylan, C., Nosaka, K., Green, J., & Cronin, J. (2011). The effect of three different start thresholds on the kinematics and kinetics of a countermovement jump. *Journal of Strength and Conditioning Research*, 25(4), 1164–1167. https://doi.org/10.1519/JSC.0b013e3181c699b9

Mizuguchi, S., "Net Impulse and Net Impulse Characteristics in Vertical Jumping" (2012). Electronic Theses and Dissertations. Paper 1459. https://dc.etsu.edu/etd/1459

Mizuguchi, S., Sands, W. A., Wassinger, C. A., Lamont, H. S., & Stone, M. H. (2015). A new approach to determining net impulse and identification of its characteristics in countermovement jumping: reliability and validity. *Sports Biomechanics, 14*(2)*,* 258–272. https://doi.org/10.1080/14763141.2015.1053514

Moir, G. L. (2008). Three different methods of calculating vertical jump height from force platform data in men and women. *Measurement in Physical Education and Exercise Science*, *12*(4), 207–218. https://doi.org/10.1080/10913670802349766

Morton, R. H., Fitz-Clarke, J. R., & Banister, E. W. (1990). Modeling human performance in running. *Journal of Applied Physiology*, *69*(3), 1171–1177. https://doi.org/10.1152/jappl.1990.69.3.1171

Mroczek, D., Kawczyński, A., & Chmura, J. (2011). Changes of reaction time and blood lactate concentration of elite volleyball players during a game. *Journal of Human Kinetics*, *28*, 73–78. https://doi.org/10.2478/v10078-011-0024-y

Newton I, Philosophiæ Naturalis Principia Mathematica (The Mathematical Principles of Natural Philosophy), London, B. Motte, 1729.

Nybo, L. (2003). CNS Fatigue and prolonged exercise: Effect of glucose supplementation: *Medicine & Science in Sports & Exercise*, *35*(4), 589–594. https://doi.org/10.1249/01.MSS.0000058433.85789.66

Nybo, L., Dalsgaard, M. K., Steensberg, A., Møller, K., & Secher, N. H. (2005). Cerebral ammonia uptake and accumulation during prolonged exercise in humans. *The Journal of Physiology*, *563*(Pt 1), 285–290. https://doi.org/10.1113/jphysiol.2004.075838

Nybo, L., & Secher, N. H. (2004). Cerebral perturbations provoked by prolonged exercise. *Progress in Neurobiology*, *72*(4), 223–261. https://doi.org/10.1016/j.pneurobio.2004.03.005

Pascal, J. R. (2020). *The Impact of a Division I Volleyball Season on Jumping Performance*. Georgia Southern University.

Pelzer, T., Schmidt, M., Jaitner, T., & Pfeiffer, M. (2020). External training load and the effects on training response following three different training sessions in young elite beach volleyball players. *International Journal of Sports Science & Coaching*, *15*(5–6), 717–727. https://doi.org/10.1177/1747954120940488

Plisk, S. S., & Stone, M. H. (2013). Periodization Strategies. *Strength and Conditioning Journal*: *National Strength and Conditioning Association*. *25*(6), 19-37.

Rodacki, A. L. F., Fowler, N. E., & Bennett, S. J. (2002). Vertical jump coordination: Fatigue effects: *Medicine & Science in Sports & Exercise*, *34*(1), 105–116. https://doi.org/10.1097/00005768-200201000-00017

Rodríguez-Marroyo, J.A., Medina, J., García-López, J., García-Tormo, J.V., & Foster, C.C. (2014). Correspondence Between Training Load Executed by Volleyball Players and the One Observed by Coaches. *Journal of Strength and Conditioning Research, 28*, 1588–1594.

Sams, ML., (2014). Comparison of static and countermovement jump variables in relation to estimated training load and subjective measures of fatigue. Electronic Theses and Dissertations. Paper 2411. https://dc.etsu.edu/etd/2411

Sahlin, K. (1986). Muscle fatigue and lactic acid accumulation. *Acta Physiologica Scandinavica Supplementum*, *556*, 83–91.

Sanders, G. J., Boos, B., Shipley, F., & Scheadler, C. M. (2018). An accelerometer-based training load analysis to assess volleyball performance. *Journal of Exercise and Nutrition Open Access*, *1*(1), 5. https://www.journalofexerciseandnutrition.com/index.php/JEN/article/view/4

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine & Science in Sports & Exercise*, *31*(4), 572–577. https://doi.org/10.1097/00005768-199904000-00013

Selye, H. (1946). The general adaptation syndrome and the diseases of adaptation. *The Journal of Clinical Endocrinology and Metabolism*, *6*(2), 117–230.

Sheppard, J. M., Cronin, J. B., Gabbett, T. J., McGuigan, M. R., Etxebarria, N., & Newton, R. U. (2008). relative importance of strength, power, and anthropometric measures to jump performance of elite volleyball players. *Journal of Strength and Conditioning Research*, *22*(3), 758–765. https://doi.org/10.1519/JSC.0b013e31816a8440

Skurvydas, A., Dudoniene, V., Kalvėnas, A., & Zuoza, A. (2002). Skeletal muscle fatigue in long-distance runners, sprinters and untrained men after repeated drop jumps performed at maximal intensity. *Scandinavian Journal of Medicine & Science in Sports*, *12*(1), 34–39. https://doi.org/10.1034/j.1600-0838.2002.120107.x

Smith, D. J., Roberts, D., & Watson, B. (1992). Physical, physiological and performance differences between Canadian national team and Universiade volleyball players. *Journal of Sports Sciences*, *10*(2), 131–138. https://doi.org/10.1080/02640419208729915

Spence, D. W., Disch, J. G., Fred, H. L., & Coleman, A. E. (1980). Descriptive profiles of highly skilled women volleyball players: *Medicine & Science in Sports & Exercise*, *12*(4), 299-302. https://doi.org/10.1249/00005768-198024000-00013

Stone, M. H. & Hornsby, G. & Haff, G. & Fry, A. & Suarez, D. & Liu, J. & Gonzalez R., Jose M. & Pierce, K. (2021). Periodization and block periodization in sports: Emphasis on strength-power training—A provocative and challenging narrative. *Journal of Strength and Conditioning Research.* Publish Ahead of Print. 10.1519/JSC.0000000000004050.

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 Sport Science Research, 5*(1).

Stone, M. H., O'Bryant, H. S., Hornsby, G., Cunanan, A., Mizuguchi, S., Suarez, D. G., South, M., Marsh, D. J., Haff, G. G., & Ramsey, M. W. (2019). Using the isometric mid-thigh pull in the monitoring of weightlifters: 25+ years of experience. *Proform. Strength Cond*, *54*, 19–26.

Stone, M., Sands, W., & Stone, M. (2007). *Principles and Practice of Resistance Training*. https://doi.org/10.5040/9781492596875

Strojnik, V., & Komi, P. V. (1998). Neuromuscular fatigue after maximal stretch-shortening cycle exercise. *Journal of Applied Physiology*, *84*(1), 344–350. https://doi.org/10.1152/jappl.1998.84.1.344

Suarez, D. G., Wagle, J. P., Cunanan, A. J., Sausaman, R. W., & Stone, M. H. (2019). Dynamic correspondence of resistance training to sport: A brief review. *Strength & Conditioning Journal*, *41*(4), 80–88. https://doi.org/10.1519/SSC.0000000000000458

Suchomel, T. J., Nimphius, S., Bellon, C. R., & Stone, M. H. (2018). The importance of muscular strength: Training considerations. *Sports Medicine*, *48*(4), 765–785. https://doi.org/10.1007/s40279-018-0862-z

Suchomel, T. J., Nimphius, S., & Stone, M. H. (2016). The importance of muscular strength in athletic performance. *Sports Medicine*, *46*(10), 1419–1449. https://doi.org/10.1007/s40279-016-0486-0

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. *Journal of Australian Strength & Conditioning, 20*(1), 13.

Tillman, M. D., Hass, C. J., Brunt, D., & Bennett, G. R. (2004). Jumping and Landing Techniques in Elite Women's Volleyball. *Journal of Sports Science & Medicine*, *3*(1), 30–36.

Travis, S. K., Ishida, A., Taber, C. B., Fry, A. C., & Stone, M. H. (2020). Emphasizing Task-Specific Hypertrophy to Enhance Sequential Strength and Power Performance. *Journal of Functional Morphology and Kinesiology*, *5*(4), 76. https://doi.org/10.3390/jfmk5040076

Uchida, M. C., Teixeira, L. F., Godoi, V. J., Marchetti, P. H., Conte, M., Coutts, A. J., & Bacurau, R. F. (2014). Does the timing of measurement alter Session-RPE in boxers? *Journal of Sports Science & Medicine*, *13*(1), 59–65.

Vlantes, T. G., & Readdy, T. (2017). Using microsensor technology to quantify match demands in collegiate women's volleyball. *Journal of Strength and Conditioning Research*, *31*(12), 3266–3278. https://doi.org/10.1519/jsc.0000000000002208

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

Wernbom, M., Augustsson, J., & Thomeé, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. *Sports Medicine (Auckland, N.Z.)*, *37*(3), 225–264. https://doi.org/10.2165/00007256-200737030-00004

Westerblad, H., Allen, D. G., & Lännergren, J. (2002). Muscle fatigue: Lactic acid or inorganic phosphate the major cause? *News in Physiological Sciences: An International Journal of Physiology Produced Jointly by the International Union of Physiological Sciences and the American Physiological Society*, *17*, 17–21. https://doi.org/10.1152/physiologyonline.2002.17.1.17

Westerblad, H., Bruton, J. D., & Lännergren, J. (1997). The effect of intracellular pH on contractile function of intact, single fibres of mouse muscle declines with increasing temperature. *The Journal of Physiology*, *500*(Pt 1), 193–204.

Zatsiorsky, V. M., & Kraemer, W. J. (2006). *Science and Practice of Strength Training, Second Edition* (Second edition). Human Kinetics.

VITA

GRAYSON TRADER FLORA

Education:	M.S. Sport Science & Coach Education, East Tennessee State University, Johnson City, Tennessee, 2020 - 2022 B.S. Exercise Science, King University, Bristol, Tennessee, 2017-2020 B.S. Exercise Science, Appalachian State University, Boone, N.C., 2015-2017
Professional Experience:	Strength & Conditioning Coach / Sport Scientist, East Tennessee State University; Johnson City, TN, 2020- Current
Publications:	Burke, Benjamin & Grupp, Nicole & Flora, G. Trader & Gentles, Jeremy. (2021). The Isometric Squat as an Indicator of Performance in Powerlifting Competition.