1-1-2023

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Recommended Citation

van den Berg, Kristel Tessa, "Acute Countermovement Jump Performance in Collegiate Distance Runners" (2023). *Electronic Theses and Dissertations*. 2890.
https://egrove.olemiss.edu/etd/2890

Acute Countermovement Jump Performance in Collegiate Distance Runners

A Thesis
presented in partial fulfillment of requirements
for the degree of Master of Science in Exercise Science
in the Department of Health, Exercise Science and Recreation Management
The University of Mississippi

by

Kristel T. van den Berg

December 2023

Abstract

Introduction: Running is the most popular form of physical activity worldwide and it has a positive effect on the overall health. However, (competitive) running is also associated with stress injuries. Stress injuries can be caused by overtraining. Countermovement jumps (CMJ) have previously been used to monitor training load and neuromuscular fatigue in athletes of multiple sports. However, this has not been explored in distance runners yet. Therefore, the purpose of this study is to assess if countermovement jump (CMJ) performance in collegiate distance athletes has a relationship to neuromuscular fatigue.

Methods: In total 12 female and 15 male distance runners from the Ole Miss cross country team performed countermovement jump (CMJ) tests before and after a workout session. Before the jumps, the athletes did 10 body weight squats as a warm-up. The CMJs were performed on the VALD ForceDecks platform. Eccentric mean force (asymmetry), peak power output and jump height measurements were taken. The athletes filled out the Perceived Recovery Status (PRS) scale and the Rating-of-Fatigue (ROF) scale before they did the CMJ tests to determine perceived fatigue.

Results: Decreases were found in perceived recovery and increases were found in rate of fatigue post workout compared to pre-workout ($p<0.05$). However, significant increases were found in jump height, power, single leg jump height and single leg power post workout compared to pre-workout ($p<0.05$). Additionally, no significant strong correlations between perceived fatigue and CMJ performance were found.

Conclusion: The results indicate that CMJs were not a predictor for neuromuscular fatigue in cross country athletes. Further studies need to be conducted in which more data is collected.

Jumps should be performed before the warm-up, after the warm-up and after the workout and after the cool-down.

Dedication

This thesis is dedicated to the Ole Miss track and field program for giving me the opportunity to study and compete for Ole Miss and for making it possible to perform my research.

List of abbreviations

1RM	1 rep max
CMJ	Countermovement jump
CI	Confidence Interval
HrV	Heart rate variability
MRI	Magnetic resonance imaging
NCAA	National Collegiate Athletic Association
PAP	Post activation potentiation
PAPE	Post-activation performance enhancement
PRS	Perceived Recovery Status
ROF	Rating-of-Fatigue
RPE	Perception of effort
VO_2	Volume of oxygen

Acknowledgement

I would like to thank all the individuals that participated in this study for their time and patience.

I would also like to thank Dr. Andre as thesis chair for giving me advice and supporting me through the process of writing my thesis.

Thank you to Dr. Loenneke, Dr. Loprinzi and Dr.Valliant for being on my thesis committee.

Thank you to Sylvio and Julia for assisting me with collecting all the data.

I am thankful for all my close friends and family who have supported me through this journey (even when I am on the other side of the world).

I am very fortunate to have such a supportive group of people around me.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

Running is one of the most popular forms of physical activity worldwide and its positive effect on the overall health is well established (Lopes et al., 2020). Running can be done leisurely or competitively, however both can have commonly associated injuries including stress fractures and tendinopathy (Kerr et al., 2016). The most common forms of these injuries are medical tibial stress fractures and Achilles tendinopathy (Tonoli et al., 2010). These injuries are mostly caused by overtraining and change of footwear (Denay, 2017; Saunier & Chapurlat, 2018). Since stress fractures and tendinopathy are mostly caused by overtraining, it is expected that competitive distance runners are at higher risk of developing these injuries. This highlights the importance of objective load monitoring in collegiate distance runners.

Different modalities of training and recovery have been explored. Strength training has been suggested as an effective method in preventing stress fractures and tendinopathy injuries (Moffit et al., 2020). Two studies that examined the effects of strength training on bone mineral density found that strength training increases bone mineral density (Kerr et al., 2016; Tonoli et al., 2010). This means strength training might have a positive effect on stress fracture prevention. Monitoring training load of the weight room sessions might be beneficial to lower the injury risk and overall fatigue of collegiate long distance runners (Hartsell & Spaulding, 1999).

Fatigue is a complex sensation involving changes in the central nervous system and internal conditions in the body (Cordeiro et al., 2017). Neuromuscular fatigue is commonly defined as any exercise-induced reduction in the ability of skeletal muscle to produce force or power over irrespective of task completion (Ratel et al., 2015). It has been suggested that not only does central fatigue explain the strength loss after prolonged running, but alterations in neuromuscular propagation are also involved. Changes in biomechanical patterns may be the cause and consequence of neuromuscular fatigue, which is also influenced by modifications in the cardiovascular and anaerobic metabolism, muscle trauma and thermal conditions. All these processes affect distance running performance (Guillaume, 2011). It has also been documented that bone strains in the lower extremity may be influenced by neuromuscular fatigue (Khassetarash et al., 2023). Potentially, load monitoring in distance athletes might assess neuromuscular fatigue early, which might help lower the overtraining injury rate and increase the distance running performance.

External and internal training load factors affect training stress of distance runners. External load factors are the physical repercussions of training performed by an athlete, these can be monitored by assessing the mileage, number of sessions and running pace of the athletes. Internal load factors are associated with be biological response of the athlete to the external load imposed by training. Examples are session rating of perceived exertion, heart rate and blood lactate level (Matos et al., 2019; Paquette et al., 2020). Countermovement jumps (CMJ) are used in multiple sports to monitor the athletes' training load accumulation for potential (neuromuscular) fatigue (Claudino et al., 2017). Previous research on the CMJ has shown a relationship between fatigue monitoring and CMJ performance in multiple sports (Ellis et al., 2022; Gathercole et al., 2015; Jiménez-Reyes et al., 2019). Current literature has not looked into the relationship between neuromuscular fatigue and CMJ in distance runners.

Purpose

The purpose of this study was to assess if countermovement jump (CMJ) performance in collegiate distance athletes has a relationship to neuromuscular fatigue. This will potentially allow coaches to better instruct athletes on when to decrease training load.

Research question

In collegiate distance athletes, is there a relationship between CMJ performance and neuromuscular fatigue?

Hypothesis

1. CMJ variables are related to neuromuscular fatigue
2. Power output and jump height will be decreased after a workout
3. Eccentric mean force (asymmetry) will be increased after a workout

Chapter II: Literature review

Distance running

The American College of Sports Medicine defines aerobic exercises as any activity that uses large muscle groups, can be maintained continuously and is rhythmic in nature (Wahid et al., 2016). The muscles activated by this type of exercise rely on aerobic metabolism to extract ATP from amino acids, carbohydrates and fatty acids. The criterion measure for aerobic capacity is the VO_{2max} (Patel et al., 2017). In addition to being the most popular physical activity worldwide, aerobic exercise is known to increase cardiovascular and mental health (Kandola et al., 2016; Okechukwu, 2019; Zhang et al., 2018; Zhao, 2022). Endurance running is a form of aerobic exercise. However, running is also routinely accompanied by the development of overuse injuries, especially in collegiate and professional runners (Lopes et al., 2020). Therefore, it is important to monitor load in distance runners. Competitive distance running can be divided into two categories; middle-distance running and long-distance running. For middle distance running (800-3,000 meters), both the aerobic system and the anaerobic system can influence performance (Brandon, 1995). For middle-distance running, the glycolytic system is used in which glucose or glycogen is broken down to lactate to generate ATP. This process occurs in the cytoplasm of the cell (Silverthorn, 2016). For long distance running (>3000 meters) the aerobic system is the limiting factor. The maximal oxygen uptake (VO_{2max}), running economy and the aerobic threshold are determinants of performance (Brandon, 1995). The aerobic system utilizes fat, carbohydrates and proteins to generate ATP (energy). This occurs in the mitochondria of the cells; the Krebs cycle and electron transport chain are included in this process. The anaerobic system can be subdivided further into two categories, the ATP-PCr system and glycolytic system.

Aerobic Training

Aerobic training is known to induce improvements in cardiovascular fitness (VO_{2max}) and mental health, which are both important factors for distance running performance (Bebetsos & Goulimaris, 2015; Raglin, 2004). The increase in cardiovascular fitness as a result of aerobic training can be explained by both structural and functional changes in the heart. Mechanical remodeling is characterized by increased performance, a moderate increase in the left ventricular mass, and by an increase in contractile force. Autonomic remodeling is characterized by a decreased resting heart rate and increased heart rate variability (HrV) indexes. Lastly, electrical remodeling is characterized by a redistribution of the activation time throughout the ventricular wall (Marocolo et al., 2007). Marocolo et al. (2007) looked at the effect of an aerobic training program on electrical remodeling of the heart in male high-performance long-distance runners compared to untrained healthy volunteers. They looked at the HrV, VO_{2max}, and signal-averaged ECG 24 hours after a training session. They found that high frequency content of the signal-averaged ECG correlates with VO_{2max}. This suggests that aerobic training does improve cardiovascular fitness via electrical remodeling. The functional and structural adaptions within the heart propagate the antiatherogenic effects. Aerobic training also has anti-inflammatory effects via a reduction in visceral fat mass and a reduction in adipokine release (Cullen et al., 2020). Furthermore, aerobic training helps with the prevention of hypertension with a meta-analysis study found that aerobic endurance training decreases blood pressure through a reduction of the vascular resistance (Cornelissen & Fagard, 2005). This shows that aerobic training reduces blood pressure, which helps increase the performance of endurance athletes. An elevated blood pressure in elite athletes leads to a decreased exercise capacity, showing how important aerobic training is for elite athletes (Mazic et al., 2015).

Endurance, interval and speed training are important for distance runners and routinely targeted during training for specific adaptations. Competitive endurance athletes monitor their training intensity to control their training load. They seem to converge on an intensity distribution of 80% of the training sessions at low intensity (blood lactate level <2mM) and 20% dominated by periods of high-intensity training (90% of VO_{2max}) such as interval training. Interestingly, there is no gold standard currently for a training method for distance runners (Seiler, 2010). There are only a few training studies that involved trained distance runners and failed to compare the runners training before and during the intervention period (Midgley et al., 2007). Research has shown that combination of altitude training and strength training improve running economy in trained distance runners (Saunders et al., 2004). However, these studies did not include different experimental groups, which makes it hard to compare the effects different training methods in relation to each other. Therefore, there is not enough evidence to formulate data driven training recommendations on speed, endurance and interval training for trained distance runners. However, other scientific knowledge such as the acute physiological responses in exercise domains that affect the physiological determinates of long-distance running does exist (Midgley et al., 2007). A literature analysis performed by Bolotin and Bakayev (2020) concluded that different type of runners should have different training methods and that it is important to monitor training load. Runners with aerobic type of provision for their muscular activity should train tempo endurance by standard continuous exercise, for speed training the by repetition method should be used. Athletes with anaerobic and mixed type of muscular activity quickly adapt to speed-strength work and should therefor train speed by the submaximal effort method. For endurance training, aerobic types should do interval exercise and mixed types should do continuous exercise. Both aerobic and anaerobic types should include strength training to their training methods. Since it has been proven that strength training allows the muscles to utilize more elastic energy and reduce the amount of energy wasted in braking forces (Saunders et al., 2004).

Strength training in distance runners

Currently, research is limited that focus on strength training in elite and collegiate distance runners. However, it is important to consider when assessing the full training load and examining the accumulation of all training that a cross country athlete will complete. Previous investigations have examined the effect of a 40-week strength training intervention on strength, running economy and velocity at maximal oxygen uptake in competitive collegiate and national-level distance runners. This strength program consisted of maximal strength (high-load, low-velocity movements), explosive strength (high-load, high velocity-movements) and reactive strength (low-load, high-velocity movements). One to three sets with three to eight repetitions were performed for the strength program, varying during the season. It was observed that 40 weeks of strength training can improve maximal (increase in weight for back squat) and reactive strength (increase in height in both countermovement jumps and drop jumps), running economy and velocity at maximal oxygen uptake. This shows that strength training affects the countermovement jump performance (Beattie et al., 2017). Additionally, the effect of strength training over an 8-week intervention compared to a control group resulted in an increase in rate of force development (improved lifting time velocity), time to exhaustion and running economy (Støren et al., 2008). Two systematic reviews on the effect of strength training on long-distance runners both concluded that strength training possibly has a positive effect on performance. Blagrove et al. (2018) found that running economy and time trial time improved in most studies reviewed but this was not consistent across all studies. These differences can be attributed to the difference in methodologies and characteristics of participants of the studies that were reviewed. Yamamoto et al. (2008) highlighted the short duration and wide range of exercises in the different studies that are included in the review are of concern. Both review papers conclude that more research is needed in the field since the results of these studies are inconsistent. Another review paper observed that strength training increased the lactate threshold in untrained individuals but not in trained endurance runners. However, they did find an increase in running economy in trained endurance runners and concluded that the effect of strength training on running performance is most likely a result of the impact it has on neuromuscular characteristics (Jung, 2003). These results are not in line with additional research that also focused on the effects of strength training on endurance capacity in top-level endurance athletes. It was noted that concurrent strength training can lead to enhanced long-term (>30 minutes) and short-term (<15 minutes) endurance capacity in well-trained and highly trained top-level endurance athletes (Aagaard & Andersen, 2010). In Aagaard & Andersens' review paper the authors mostly focused on high-volume, heavy resistance training, which might explain the conflicting results to Jung's review paper.

Several studies have been performed on the effects of high repetition strength training on endurance performance. A recent systemic review and meta-analysis paper found that high-repetition strength training did not improve performance in competitive endurance athletes over a 4- to 12-week period. They concluded that future studies should be > 12 weeks in duration to possibly see an effect (Nugent et al., 2022). Additionally, the effects of explosive and high-resistance training on performance was examined over 4-5 weeks. The experimental group replaced their usual training with twelve 30-minute sessions consisting of 3 sets of explosive single leg jumps alternating with 3 sets of high-resistance cycling sprint. It was found that the addition of explosive training and high-resistance interval training to the programs of well-trained cyclists causes substantial improvements in both sprint and endurance performance (Paton & Hopkins, 2005). Given distance running is a very injury sensitive sport, with stress fractures being the number one injury in cross country athletes (Kerr et al., 2016; Tonoli et al., 2010), this may be one potential method to reduce injury rates. A study on the effect of maximal strength training on bone mineral density in young adult women found that 12 weeks of maximal strength training improved bone mineral density compared to following the American College of Sports Medicine's exercise guidelines for 12 week (Mosti et al., 2014). These results suggest that strength training could potentially be utilized within this population for performance enhancement and injury prevention. These results also show that it is important to take strength training into consideration when assessing the training load. However, research is currently limited on the effect of strength training on injury prevention in elite distance runners.

Injury rates

Considering that monitoring athlete fatigue is the sum of all activities ranging from their sport specific training and supplementary training including strength training, it is important to examine resulting injuries associated with the sport. Common injuries that are found in distance runners are stress fractures and tendinopathy (Kerr et al., 2016). Stress fractures are small cracks in the bones which occur as a result of a disturbance in the equilibrium of bone resorption and synthesis (Shaker, 2018). A stress fracture can mean the end of the season or even the career and female distance runners are at the greatest risk of developing stress fractures (Rizzone et al., 2017). Tendinopathy is a failed healing response of the tendon and degeneration of the collagen protein that forms the tendon and a subsequent increase in non-collagenous matrix (Maffulli et al., 2010). Symptoms are chronic, localized and load-dependent tendon pain, loss of optimal function and tendon thickening (Maffulli et al., 2020; Mousavi et al., 2019).

Respectively, the most common forms of these injuries are medial tibial stress fractures and achilles tendinopathy (Tonoli et al., 2010). These injuries are mostly caused by overuse/overtraining with the subsequent risk factors for injuries including: high training intensity, hard surface training and change of footwear (Denay, 2017; Saunier & Chapurlat, 2018). An epidemiological study (Kerr et al., 2016) was performed on the National Collegiate Athletic Association (NCAA) men's and women's cross-country injuries during the 2009-2010 through 2013-2014 academic years. During this time period, 216 injuries in men and 260 in women were observed, leading to an injury rate of 4.66/1000 athlete-exposures for men an injury rate of 5.85/1000 athlete-exposures for women. Interestingly the authors noted the majority of the injuries that were found were stress fractures or tendinopathy in the lower extremity. Tenforde et al. (2017) focused on the association between the female athlete triad and development of bone stress injuries in female collegiate athletes. It was found that athletes with moderate to high risk for the female athlete triad were more likely to get a bone stress injury and cross country having the highest risk of all sports examined. Another study performed in Division I cross-country runners found that all the runners who had a history of stress fractures did not meet their daily recommended energy intake or adequate intakes for calcium and vitamin D (Griffin et al., 2021).

There is no consensus over the best way to treat tendinopathy, however, current evidence suggests a progressive loading program, rather than complete rest (Cardoso et al., 2019). Eccentric exercises in combination with shock wave therapy is a common used method to treat patients who are diagnosed with tendinopathy (Mousavi et al., 2019). However, the effect of eccentric exercise on the recovery of tendinopathy is taken into consideration since recent studies found no effects (Cardoso et al., 2019; Malliaras et al., 2013). Eccentric-concentric loading might be a more effective form of treatment (Malliaras et al., 2013). People who suffer from Achilles tendinopathy demonstrated strength deficits in high-load, low-velocity movements, medium-load, high velocity movements, and low-load, high-velocity movements (McAuliffe et al., 2019). Hartsell and Spaulding (1999) showed that the eccentric/concentric ratios are dependent on velocity, suggesting that testing modalities that monitor this may provide a potential method to monitor athlete risk of injury and overall fatigue

Fatigue

Fatigue is a complex sensation involving changes in the central nervous system and internal conditions in the body. (Cordeiro et al., 2017). During physical exercise, metabolites and heat are generated, which affect the steady state of the internal environment. Depletion of energy sources will cause perceived fatigue and exhaustion, causing the subject to adapt his or her exercise strategy. These sensations are essential for maintaining physical health (Ament & Verkerke, 2009). The primary factors for fatigue in prolonged aerobic exercise are exercise intensity and duration, environmental conditions, diet, and fitness level of the individual (Cordeiro et al., 2017). Williams et al. (1991) examined changes in distance running kinematics with fatigue in collegiate distance runners. Changes in kinematics with fatigue were investigated during intercollegiate competition, a noncompetitive track run and a constant speed treadmill run. Regression equations for each individual were generated from non-fatigue data. With increasing fatigue, subsequent increases in step length, maximal knee flexion angle during the swing phase, and maximal thigh angle during hip flexion were observed. These changes were of different for the separate individuals. These results might indicate that fatigue affects the maximal performance of the latter stages. Further investigations into the effects of prolonged running on the symmetry of biomechanical variables of the lower limb joints have occurred in healthy male amateur runners. It was observed that the symmetry of the knee flexion angle, hip flexion angle and hip extension angle in post-fatigue was significantly greater than in pre-fatigue. Moreover, the symmetry angle of hip flexion moment increased. However, the knee extension velocity and hip flexion velocity became more symmetrical than in pre-fatigue. These results indicate that the variables of asymmetry may be used as a compensation mechanism to maintain gait stability. The authors suggested fatigue may potentially cause injuries due to these changes in symmetry (Gao et al., 2020). Further research has examined the effects of 30- minute treadmill running (85% maximal aerobic speed) and fatigue on impact acceleration in recreational runners. It was found that fatigue when running overground decreased impact acceleration severity, but it had no effect when running on the treadmill (García-Pérez et al., 2014). Recently Willer et al. (2021) examined neuromechanics of fatigue in competitive male and female middle-distance runners, focusing on the lower limbs, Fatigue was determined at a 3-minute high-intensity run to fatigue based on their VO_{2max}. Three-dimensional kinematics and kinetics were collected at different time points in this run to fatigue. Measurements were performed at the start, 33% into the run, 67% into the run and at the finish. Next to that, the activation of eight lower limb muscles of each leg was measured with surface EMG. They found that running at a constant middle-distance pace led primarily to the fatigue of plantar flexors with a compensatory increase in positive work done at the knee. No change in positive hip extension was found. However, and increase in hip extensor EMG amplitude was found in the late wing phase. Thus, improving fatigue resistance of the planar flexors might positively affect middle-distance running performance (Willer et al., 2021). This study shows that neuromechanics are affected by fatigue. Given the previous research above describe multiple effects fatigue can have on running form and performance, the need to assess fatigue suggests additional investigations within this concept.

Neuromuscular fatigue

Neuromuscular fatigue can be defined as any exercise-induced reduction in the ability of skeletal muscle to produce force or power over irrespective task completion (Ratel et al., 2015). Neuromuscular fatigue can be measured by looking at maximal voluntary contractions, peak twitch contraction time, and total area of mechanical response (Lepers et al., 2002). It has been proven that not only central fatigue explains the strength loss after prolonged running, alterations in neuromuscular propagation are also involved. Changes in biomechanical patterns may be the cause and consequence of neuromuscular fatigue, which is also influenced by modifications in the cardiovascular and anaerobic metabolism, muscle trauma and thermal conditions. All these processes affect distance running performance (Guillaume, 2011). A study performed on elite female soccer players examined the time course of recovery from neuromuscular fatigue from soccer matches separated by an active and passive recovery regime. Countermovement jumps (CMJ) were reduced after the first soccer match and still reduced at the start of the second match in both the active and passive recovery groups. This suggests within this population that active recovery does not affect the time course of recovery of neuromuscular fatigue (Andersson et al., 2008). However, prematch neuromuscular performance (assessed via CMJ) has been shown to affect running performance (speed and accelerations) in collegiate female soccer players. They found a positive relationship between CMJ performance and running performance. Pre-match relative peak power of the CMJ predicted variances in average high-speed running ($p=0.001$) (Ishida et al., 2023). These two studies show that neuromuscular fatigue might affect performance.

Neuromuscular and biochemical adaptions in the musculoskeletal system are contributing to the postactivation potentiation (PAP) phenomenon. PAP refers to the phenomenon that enhances muscular power and, consequently, performance as a result of previous muscular work. PAP is induced by a voluntary contraction as condition activity and has been show to increase power during subsequent contractions of the muscle fibers (García-Pinillos et al., 2015). This enhancement can be attributed to regulatory light chain phosphorylation and increased recruitment of motor units. The most common indicator of PAP is increased evoked isometric twitch force observed following an evoked isometric tetanic contraction. (Lorenz, 2011). One of the factors affecting PAP is the intensity; the higher the intensity, the more effective. (Esformes et al., 2010). The persistence of PAP is significant for less than 3 minutes (Vandervoort et al., 1983), however the peak of voluntary performance enhancement occurs 6 to 10 minutes after the conditioning activity (Wilson et al., 2013). Changes in muscle temperature, muscle water content and muscle activation may partly support voluntary enhancement. This enhancement has recently been named post-activation performance enhancement (PAPE). PAP is measured as the torque evoked during a twitch contraction, whereas PAPE is measured as the torque during a voluntary contraction (Blazevich & Babault, 2019). Garcia-Pinillos et al. (2015) showed that male long-distance runners could maintain their strength and power levels (CMJ height stayed similar) despite induced fatigue for extended interval training. This shows that not only metabolic adaptions but also specific neuromuscular adaptions affect performance in long-distance runners. Potentially, load monitoring in distance athletes might indicate neuromuscular fatigue, which might help lower the overtraining injury rate.

Load monitoring in distance runners

Training stress is affected by external and internal training load factors. External load factors are the physical repercussions of training performed by an athlete. Internal load is associated with the biological response of the athlete to the external load imposed by training (Matos et al., 2019). External monitoring in distance runners is typically a product of multiple factors including mileage, number of sessions, and pace. Internal load factors include session rating of perceived exertion, heart rate and blood lactate level (Paquette et al., 2020). However, the most traditional modality for monitoring load is recording the weekly mileage (DeJong Lempke et al., 2022). Weekly mileage is valuable since it comprises some aspects of the neuromuscular, cardiovascular and psychological loads that contribute to training stress and is predicate of distance-running success (Paquette et al., 2020). For example, collegiate cross-country athlete's weekly mileage ranges from 75 to 105 miles in males and 55 to 75 miles in females. Furthermore, within this paradigm of weekly training load in distance runners the frequency of training is also considered (Sanchez, 2020). Essentially not focused as much on the total mileage but on the number of training sessions athletes may complete (Example: 7 to 11 times a week in collegiate cross-country). Intensity is another factor that is considered in combination with either the mileage or number of sessions per week. Intensity of the training can be examined through multiple methods including perceived exertion (RPE) scale (Sanchez, 2020), heart rate, and heart rate variability (HrV) during the workout and daily (Brockmann & Hunt, 2023). For example, HrV (R-R intervals) will decrease as exercise intensity and duration increase whereas hear rate will increase with exercise intensity. Matos et al. (2019) looked at the training loads and the athlete perception of well-being in male recreational trail runners. Small correlations between training load parameters (mileage, perception of effort), well-being and fatigue were observed. Correlations between the well-being variables and subjective RPE that were significant were those between RPE and sleep (r=0.287), stress and RPE (r=0.217), fatigue and RPE (r=0191), muscle soreness and RPE (r=0.240) and perception of well-being and RPE (r=0.279). This suggests that load monitoring might help to increase the athletes' well-being, potentially decrease fatigue and lead to increase performance (Matos et al., 2019). Currently, weekly mileage is the most used training metric to quantify load in distance running. With increasing technology that quantifies external load beyond volume or pace, the future of load monitoring should have an emphasis on neuromuscular external load metrics (Paquette et al., 2020). CMJs are used in multiple sports to see difference in load monitoring and (neuromuscular) fatigue, however has been less explored in distance runners.

Countermovement jumps

CMJs are routinely implemented to monitor athlete training load accumulation for potential fatigue due to weekly mileage, weight room sessions and intensity training (Claudino et al., 2017). The CMJ can be reported by different kinematic variables such as jump height, peak power, relative power, peak velocity, peak force, eccentric/concentric time and contraction time (Beattie et al., 2017; Claudino et al., 2017). Previous research has been performed on the relationship between fatigue monitoring and CMJ performance in multiple sports. It was shown that loss in jump height is an indicator of fatigue during sprint training

(Jiménez-Reyes et al., 2019). Another study showed that CMJ performance was correlated to training load in elite female rugby athletes. Intensified training decreased CMJ output and altered CMJ mechanics, indicating that longitudinal neuromuscular fatigue monitoring of team-sport athletes appears improved through CMJ mechanics analysis (Gathercole et al., 2015). A study performed in male soccer players found a dose-response relationship between training-load measures and changes in force-time components of the CMJ (Ellis et al., 2022). These three studies show that CMJ can be used in multiple sports as a way to monitor fatigue. Previous research has utilized CMJ to evaluate stress and (neuromuscular) fatigue from specific training sessions of a professional 800m runner. The CMJ was found to be a valid indicator of the degree of stress or fatigue generated by specific training sessions within a single session or a week (Marco-Contreras et al., 2021). Another study used the CMJ to assess explosive power of the lower extremities in middle distance runners (Maćkała et al., 2015). These two uses of the CMJ show that the CMJ is a valid method to track power and training stress in middle-distance runners. Single leg CMJs are also used to assess the unilateral power output of field and court sport athletes (Donskov et al., 2021). It has been shown that single leg CMJ height is associated with isokinetic extension strength (Fischer et al., 2017). Alternatively, the drop jump is also routinely used to examine fatigue induced from training and is a measurement of the fast stretch-shorting cycle, rate of force development and leg extensor muscle function. Changes in these variables over a season often indicate fatigue or over training (Beattie et al., 2017; Pedley et al., 2017).

The current literature indicates that CMJ is an indicator of neuromuscular fatigue in multiple sports. Given distance running is the sport with the most bone stress injuries as a result of overtraining, objective load monitoring in distance athletes is of value. CMJ performance possibly indicates neuromuscular fatigue in distance runners, but current literature has not investigated the relationship between neuromuscular fatigue and CMJ in distance runners. This highlights the need for more studies in this research field.

Chapter III: Methodology

Participants

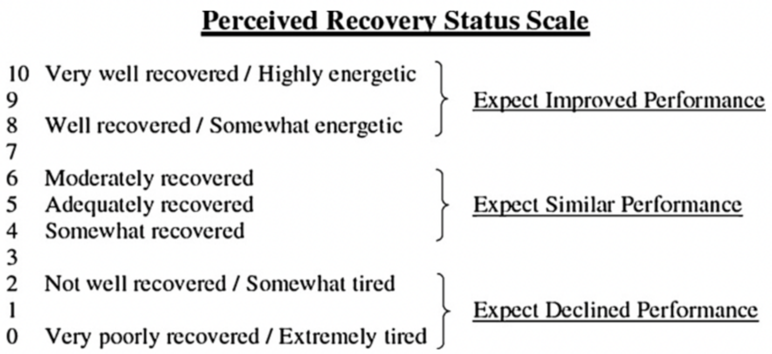
A total of 27 distance athlete's (15 male, 12 female) aged between 18-25 from the Ole Miss Cross Country team were utilized. One athlete did not complete all jumps and was excluded from the study. Each participant signed the FERPA form, which was approved by the IRB of the University of Mississippi. The coaching staff for cross-country tracks total miles per week run per athlete and the strength and conditioning staff monitors CMJ testing. The weekly mileage of the athletes for the week that the jumps were performed ranged from 40 to 100 miles for males and 45 to 70 miles for females. The day before testing the athletes had an easy run ranging from 5 to 10 miles. The testing was performed the day of a tempo workout. The athletes started with 10 bodyweight squats followed by the CMJs. After the CMJs were performed, the athletes filled out the rate-of-fatigue scale and the perceived recovery status scale. Then the athletes started their regular warm-up, the female distance athletes did a 20-minute easy run and the male distance athletes did a 3-mile easy run. Followed by the easy run the athletes did some stretches and strides. The workout consisted of a 3-to-4.5-mile tempo (at threshold pace) followed by 4 sets of 45 seconds at a higher speed for the female distance athletes. The male runners did a 3-to-5-mile tempo (threshold pace) followed by 5 sets of 45 seconds at a higher speed. All the athletes did 15-minute cooldown after they finished the session. The athletes rested for 5 minutes after the cooldown and did 10 bodyweight squats. After the squats the athletes did the CMJs and filled out the scales again.

Countermovement jumps

A CMJ test was performed pre and post workout. All participants had previously completed CMJ testing and were familiar with the test. Participants completed 10 bodyweight squats as a standardized warmup and repeated this five minutes post workout prior to all jumps. Participants completed three CMJs and two single leg CMJs per leg for each time point (pre and post). Athletes performed the CMJs with their shoes on. The participants were instructed to keep their hands placed on their hips during the jumps and aim for maximal jumping height. The CMJs were performed on the VALD ForceDecks (Brisbane, Queensland, Australia) platform (1000Hz). Asymmetry was determined by eccentric mean force, peak power output, and jump height measurements were taken.

Perceived Recovery Status Scale and Rating-of-Fatigue Scale

Prior to the CMJs, the participants filled out the perceived recovery status scale (PRS scale) (Laurent et al., 2011) and the Rating-of-Fatigue scale (ROF scale) (Micklewright et al., 2017) to determine their perceived fatigue. Before they filled out the scales, they were given instructions on how to fill them out and they were familiarized with the testing. See Figure 1 for the PRS scale see Figure 2 for the ROF scale.

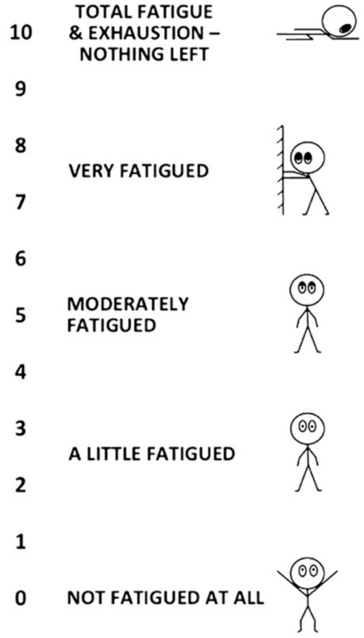


Perceived Recovery Status Scale

10 Very well recovered / Highly energetic
9
8 Well recovered / Somewhat energetic
7
6 Moderately recovered
5 Adequately recovered
4 Somewhat recovered
3
2 Not well recovered / Somewhat tired
1
0 Very poorly recovered / Extremely tired

Expect Improved Performance
Expect Similar Performance
Expect Declined Performance

Figure 1: Perceived Recovery Scale



10 TOTAL FATIGUE & EXHAUSTION – NOTHING LEFT
9
8 VERY FATIGUED
7
6
5 MODERATELY FATIGUED
4
3 A LITTLE FATIGUED
2
1
0 NOT FATIGUED AT ALL

Figure 2: Rate of Fatigue Scale

Statistical analysis

All data was reported as the mean ± standard deviation. A Shapiro-Wilk test of normality was used prior to data analysis to examine for normality of each variable. CMJ variables and weight were examined comparing pre/post aerobic training utilizing a paired samples t-test. For CMJ data that was not normally distributed and for the fatigue scales, a Wilcoxon Signed Rank test was used. The relationships between the criterion variables were analyzed through Spearman's (rho) rank order correlation coefficient. When ranking the data, in the case of ties, the tied observations receive the same average rank. For example, if three observations of X are tied for the third smallest value, the ranks involved are 3, 4, and 5. The average of these three ranks is 4, and that is the rank that each of the three observations would be assigned. The 95% confidence intervals (CIs) for the correlation coefficients were calculated for each variable The magnitude of the strength of the associations was considered very weak if Spearman's rho values are between 0-0.20, weak if between 0.21-0.40, moderate if between 0.41-0.60, strong if between 0.61-0.80, and very strong if between 0.81-1 (Prion & Haerling, 2014). The subjective scales were analyzed using the non-parametric paired Wilcoxon test. Statistical analysis was performed using Statistics Package for the Social Sciences SPSS (version 29.0, SPSS Inc. Chicago, IL) and $p< .05$ as a statistical significance criterion.

Chapter IV: Results

Mean values and confidence intervals data are reported for male participants pre and post workout (Table 1), A paired sample t-test on all the normally distributed data found significant increases in power (p=0.028), single leg height left and right (p<0.001;p=0.001) and single power left and right (p<0.001; p=0.004) in males (see Table 1).

Table 1: Results paired sample t-test of the CMJ and single CMJ variables (male athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Mean difference post-pre ± SD [95%CI]	Effect size (Cohen's d)	Two-sided p-value
Height (cm)	29.33±4.83 [26.66,32.01]	30.80±4.22 [28.46,33.14]	1.47±2.97 [-0.181, 3.11]	0.49	0.077
Power (W)	3117.47±550.50 [2812.61,3422.32]	3247.20±530.71 [2953.30,3541.10]	129.73±204.78 [16.33, 243.14]	0.63	0.028
Asymmetry[a] (N)	9.45±5.95 [6.15,12.74]	7.62±9.03 [2.62,12.62]	-1.83±8.15 [-6.34, 2.69]	-0.224	0.140
Height single leg left (cm)	13.27±2.71 [11.76,14.77]	15.58±2.61 [14.14,17.02]	2.31±1.07 [1.72, 2.91]	2.16	<0.001
Power single leg left (W)	1954.33±345.95 [1762.75,2145.92]	2123.07±324.93 [1943.12,1302.01]	168.73±89.13 [119.37, 218.09]	1.89	<0.001
Height single leg right (cm)	12.98±1.67 [12.06,13.90]	15.41±2.86 [13.83,17.00]	2.43±2.35 [1.13, 3.73]	1.04	0.001
Power single leg right (W)	1914.20±273.57 [1762.70,2065.70]	2060.13±311.28 [1887.75,2232.51]	145.93±166.20 [53.89, 237.97]	0.88	0.004

a=Wilcoxon signed rank test; data not normally distributed, n=15

Mean values and confidence intervals data are reported for female participants CMJs pre and post (Table 2). Table 2 shows the results of the paired sample t-test and Wilcoxon signed ranked test performed on the female variables. Significant increases were found in height (p=0.012), power (p=0.03) and single height left (p=0.028).

Table 2: Results paired sample t-test of the CMJ and single CMJ variables (female athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Mean difference post-pre ± SD [95%CI]	Effect size (Cohen's d)	Two-sided p-value
Height (cm)	21.59±2.61 [19.94,23.25]	23.30±4.04 [20.73,25.87]	1.71±1.97 [0.46, 2.96]	0.87	0.012
Power ^{a}(W)	1965.50±180.74 [1850.66,2080.34]	2101.08±213.42 [1965.48,2236.68]	135.58±82.72 [82.03, 188.14]	1.64	0.03
Asymmetry (N)	9.63±7.22 [5.03,14.22]	8.78±8.05 [3.67,13.90]	-0.84±4.88 [-3.94, 2.26]	-0.172	0.562
Height single leg left (cm)	9.54±1.49 [8.58,10.48]	10.52±1.89 [9.31,11.72]	0.98±1.35 [0.12, 1.84]	0.73	0.028
Power single leg left (W)	1177.08±102.28 [1112.10,1242.07]	1251.42±132.03 [1167.53,1335.30]	74.33±144.61 [-17.54, 166.21]	0.51	0.103
Height single leg right (cm)	10.28±2.08 [8.95,11.60]	11.01±2.28 [9.56,12.46]	0.73±1.99 [-0.53, 2.00]	0.37	0.228
Power single leg right (W)	1236.42±164.46 [1131.92,1340.91]	1320.92±201.83 [1192.68,1449.15]	84.50±137.62 [-2.94, 171.94]	0.61	0.57

a=Wilcoxon signed rank test; data not normally distributed, n=12

Mean values and confidence intervals data are reported for all participants CMJs pre-post (Table 3). The paired sample t-tests and Wilcoxon Signed ranked test performed on all the data found significant increases in jump height (p=0.003), power (p<0.001), single leg height left and right (p<0.001) and single leg power left and right (p<0.001). See Table 3 for these results.

Table 3: Results paired sample t-test of the CMJ and single CMJ variables (all athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Mean difference post-pre ± SD [95%CI]	Effect size (Cohen's d)	Two-sided p-value
Height (cm)	25.89±5.55 [23.70,28.09]	27.47±5.56 [25.27,29.67]	1.57±2.53 [0.57,2.58]	0.62	0.003
Power^{a} (W)	2605.58±719.21 [2320.97,2890.00]	2737.81±712.56 [2455.93,3019.70]	132.33±159.64 [69.18,195.58]	0.83	<0.001
Asymmetry^{a} (N)	9.53±6.42 [6.99,12.06]	8.14±8.47 [4.79,11.49]	-1.39±6.79 [-4.07,1.30]	-0.205	0.140
Height single leg left (cm)	11.61±2.91 [10.46,12.76]	13.33±3.43 [11.97,14.69]	1.72±1.36 [1.19, 2.26]	1.27	<0.001
Power single leg left^{a} (W)	1608.89±473.05 [1421,76,1796.02]	1735.67±508.96 [1534.33,1937.00]	-26.78±124.14 [77.67,175.88]	1.02	<0.001
Height single leg right (cm)	11.78±2.28 [10.88,12.68]	13.46±3.40 [12.11,14.80]	1.68±2.32 [0.76, 2.60]	0.72	<0.001
Power single leg right (W)	1612.96±411.75 [1450.08,1775.84]	1731.59±457.73 [1550.52,1912.67]	118.63±154.45 [57.53, 179.73]	0.77	<0.001

a=Wilcoxon signed rank test; data not normally distributed, n=27

Figure 3 shows the differences in CMJ height and single leg jump height in male athletes, female athletes and all athletes pre workout compared to post workout. Figure 4 pictures the differences in CMJ power and single leg jump power pre and post workout in male athletes, female athletes and all athletes. In all groups the jump height and power increase post workout compared to pre workout.

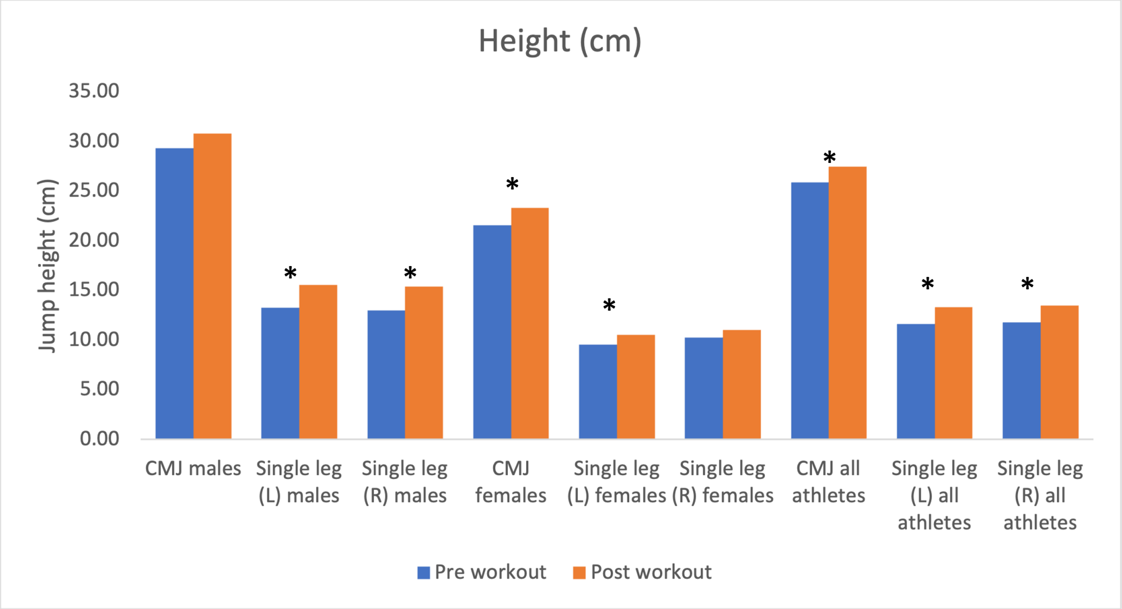


*Figure 3: Jump height of the CMJs pre and post workout and single leg jumps in male athletes, female athletes and all athletes. *=Significant increase in height*

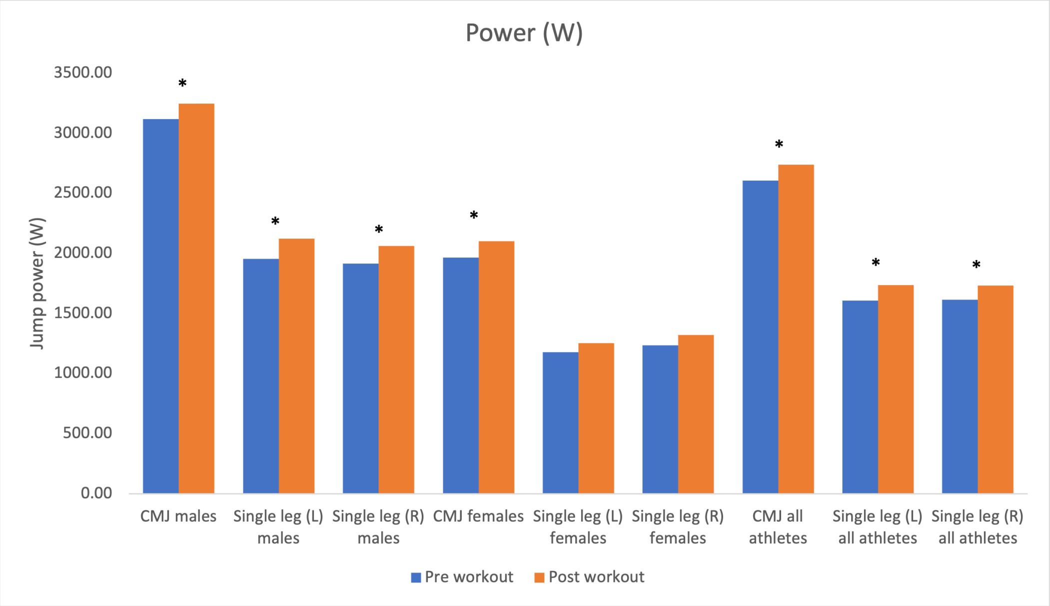


*Figure 4: Jump power of the CMJs pre and post workout and single leg jumps in male athletes, female athletes and all athletes. *=Significant increase in power*

Mean values and confidence intervals data are reported for male participants for Perceived Recovery Scale (PRS), and Rate-of-Fatigue Scale (ROF) pre and post workout (Table 4). The Wilcoxon signed rank test found a significant increase in ROF (p=0.003) and a significant decrease in PRS (p=0.005). The results of a Wilcoxon signed rank test performed on PRS and ROF data on female participants are shown in Table 5. A significant increase was found in ROF (p=0.002) and a significant decrease was found in PRS (p=0.002). Mean values and confidence intervals data are reported for all athletes PRS and ROF (Table 6). A Wilcoxon signed rank test found a significant increase in ROF (p<0.001) and a significant decrease in PRS (<0.001).

Table 4: Results Wilcoxon signed rank test of ROF and PRS (male athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Two-sided p-value
ROF	3.60±1.45 [2.79,4.41]	5.67±1.63 [4.76,6.57]	0.006
PRS	6.00±1.69 [5.06,6.94]	4.07±1.98 [2.97,5.16]	0.01

Notes: ROF (0= not fatigued at all, 10=total fatigue), PRS (0=very poorly recovered, 10 =very well recovered) n=15

Table 5: Results Wilcoxon signed rank test of ROF and PRS (female athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Two-sided p-value
ROF	2.58 ±1.00 [1.95,3.22]	5.50±1.31 [4.67,6.34]	0.004
PRS	6.17±1.19 [5.41,6.92]	3.83±0.94 [3.24,4.43]	0.004

Notes: ROF (0= not fatigued at all, 10=total fatigue), PRS (0=very poorly recovered, 10 =very well recovered) n=12

Table 6: Table 4: Results Wilcoxon signed rank test of ROF and PRS (all athletes)

	Mean Pre ± SD [95%CI]	Mean Post ± SD [95%CI]	Two-sided p-value
ROF	3.15±1.35 [2.61,2.68]	5.59±1.47 [5.01,6.18]	<0.001
PRS	6.07±1.47 [5.49,6.65]	3.96±1.58 [3.34,4.59]	<0.001

Notes: ROF (0= not fatigued at all, 10=total fatigue), PRS (0=very poorly recovered, 10 =very well recovered) n=27

A Spearman Rank correlation on the CMJ data of the male athletes revealed that there was a moderate significant correlation between net change in height and net change in asymmetry (0.572, p=0.026). Strong significant correlations were also found between net change in power and net change in perceived recovery (0.631, p=0.012) and between net change in rate of fatigue and perceived recovery (-0.722, p=0.002). See Table 7 for all the correlations found in male athletes.

Table 7: Correlations for changes of the CMJ and scale variables in male athletes

	Net change height	Net change power	Net change asymmetry	Net change ROF	Net change PRS
Net change height	1.000	-	0.572*	-0.226	0.450
Net change power	-	1.000	0.496	-0.289	0.631*
Net change asymmetry	0.572*	0.496	1.000	-0.056	0.234
Net change ROF	-0.226	-0.289	-0.056	1.000	-0.722*
Net change PRS	0.450	0.631*	0.234	-0.722*	1.000

*= correlation is significant

For female athletes, a very strong correlation was found between the net change in rate of fatigue and the net change in perceived recovery (-0.861, p<0.001) (Table 8).

Table 8: Correlations for changes of the CMJ and scale variables in female athletes

	Net change height	Net change power	Net change asymmetry	Net change ROF	Net change PRS
Net change height	1.000	-	0.077	-0.438	0.468
Net change power	-	1.000	0.007	-0.185	0.201
Net change asymmetry	0.077	0.007	1.000	-0.182	0.421
Net change ROF	-0.438	-0.185	-0.182	1.000	-0.861*
Net change PRS	0.468	0.201	0.421	-0.861*	1.000

*= correlation is significant

Lastly, a Spearman Rank correlation was performed on both male and female CMJ data. A moderate significant correlation was found between net change in height and net change in perceived recovery (0.415, p=0.031). Additionally, a moderate significant correlation was found between net change in power and net change in perceived recovery (0.406, p=0.036). Lastly, a strong significant correlation was found between the net change in rate of fatigue and the net change in perceived recovery (-0.780, p<0.001). See Table 9 for all the correlations found in both male and female athletes.

Table 9: Correlations for changes of the CMJ and scale variables in all athletes

	Net change height	Net change power	Net change asymmetry	Net change ROF	Net change PRS
Net change height	1.000	-	0.277	-0.267	0.415*
Net change power	-	1.000	0.283	-0.200	0.406*
Net change asymmetry	0.277	0.283	1.000	0.116	0.129
Net change ROF	-0.267	-0.200	0.116	1.000	-0.780*
Net change PRS	0.415*	0.406*	0.129	-0.780*	1.000

*= correlation is significant

Mean values and confidence intervals data are reported for bodyweight (BW) of the athletes pre and post workout (Table 10). A paired sample t-test found significant decreases in BW post workout compared to pre workout in male athletes, female athletes and all athletes combined (p<0.001).

Table 10: Results paired sample t-test of pre and post workout bodyweight

	Mean Pre BW (kg) ± SD [95%CI]	Mean Post BW (kg) ± SD [95%CI]	Mean difference post-pre BW (kg) ± SD [95%CI]	Effect size (Cohen's d)	Two-sided p-value
Males	71.22±6.61 [67.56,74.89]	69.73±6.56 [66.08,73.38]	-1.49±0.35 [-1.69,-1.30]	0.353	<0.001
Females	54.45±4.00 [51.91,57.00]	53.72±3.92 [51.23,56.21]	-0.74±0.28 [-0.92,-0.56]	0.284	<0.001
All athletes	63.77±10.12 [59.77,67.78]	62.61±9.78 [58.75,66.49]	-1.16±0.50 [-1.35,-0.96]	0.498	<0.001

Chapter V: Discussion

The main purpose of this study was to determine if CMJ performance in collegiate distance runners has a relationship to acute neuromuscular fatigue. Neuromuscular fatigue is a possible risk factor for injuries and understanding this could assist athletes and coaches. Overall, the athletes performed better on the CMJs post workout compared to before the workout. Table 1, 2 and 3 show that there were significant increases in height, power, single leg height and single leg power. Yet, the rate-of-fatigue scale and perceived recovery scale indicated that the athletes felt more fatigued post workout (Table, 4,5 and 6). It was expected that the CMJ variables would decrease post workout, since the workout was hard enough to result in fatigue in the athletes. A possible explanation for the increased performance of the CMJ's could be the shorter duration of the warm-up in the current investigation. The athletes performed 10 bodyweight squats prior to CMJ attempts. Although, the jumps were performed before the 2-mile warm-up (8:00 per mile pace) in an effort to examine the cumulative impact of the warm up and workout. Previously the impact of different warm-up protocols on CMJ performance in male collegiate athletes observed that cardiovascular activity for the duration of 5 to 10 minutes increased CMJ height. Although, static stretching did not increase jump height (Holt & Lambourne, 2008). Additional investigations that focused on the effect of different warm-ups on CMJ performance found that weighted resistance-jumping warm-up (49.38cm) compared to submaximal vertical jumping (47.75cm), stretching (48.18cm) and no warm-up (46.81) produced the highest CMJ performance. Although, it was also observed that performing any type of warm-up is better than no warm-up (Burkett et al., 2016). This potentially indicates that the 10 bodyweight squats that the participants completed in the current investigation performed were better than no warm-up at all while not increasing the training mileage. However, the purpose of the CMJ utilization is to examine the load accumulated from a training session, which in theory would include the warm up mileage and intensity within the training load. This is similar to a previous work by Malone et al. (2015) on elite youth soccer players and by Troester et al. (2019) on professional rugby players that included the warm up within the training load. Malone et al. (2015) did not find significant differences in jump height pre and post training sessions. Troester et al. (2019) found that jump height and rate of velocity of the non-dominant leg were slightly impaired post training, and rate of force development was impaired post training.

Previous studies that examined the relationship of CMJ performance to neuromuscular fatigue observed CMJ height was related to neuromuscular fatigue in distance runners (Maćkała et al., 2015; Marco-Contreras et al., 2021). Studies in other sports found the same results (Ellis et al., 2022; Gathercole et al., 2015; Jiménez-Reyes et al., 2019). These results are not in line with our study. An explanation for the different results in our study could be PAPE. Moré et al. (2023) looked at the effects running at different intensities on PAPE responses in active and recreational runners. They found enhancement in CMJ performance in active individuals when running at 70% of maximum aerobic speed. Since the workout that was done by the athletes was a tempo session, which is at an aerobic level, PAPE might have influenced the increased CMJ performance in our study. Furthermore, in female volleyball players found that CMJ performance was increased post-PAPE compared to pre-PAPE. In this study the activation protocol consisted of 4 minutes of aerobic running, 4 minutes of dynamic stretching, 2 minutes of speed and 5 consecutive CMJ jumps. Our workout also consisted of stretching, aerobic running and some speed in the end of the workout (Villalon-Gasch et al., 2022). These two studies show another potential explanation for the CMJ performance being increased post aerobic training. A study showed that in elite long-distance runners an intensive prolonged running exercise reduces the surface EMG of the knee extensor muscles, which may lead to a different coordination strategy in leg extension exercises performed in vertical direction, which would be the CMJ (Vuorimaa et al., 2006). This might have affected the jumps in the current study as well, since the athletes jumped before the team warm-up. However, in the current study EMG was not investigated. Vuorimaa et al. (2006) also found that after continuous type of running (40 minutes at 80% of VO_{2max}), the power improvement correlates positively with maximal endurance running capacity. Which means that with a greater endurance capacity, there is a power improvement and thus an increase in CMJ performance. Since in the current investigation the aerobic workout was a tempo, (type of continuous running), and the athletes have great maximal endurance capacity the power improvement and thus the CMJ performance might be increased after the workout compared to before the workout.

It was expected that positive correlations would be found between net change in PRS and the net change in the CMJ variables and that negative correlations would be found between the net change in ROF and the net change in the CMJ variables (Table 7, 8 & 9). Correlations were found between multiple net changes, however the correlations between these variables were not significant or only moderate. An explanation for this could be the difference between performance fatigue (neuromuscular fatigue) and perceived fatigue (ROF-scale). The assumption that adjustments in neuromuscular activity are needed to counteract an exercise-induced decrease in force capacity and thereby sustain CMJ performance is independent from the associated sensations. Next to that, most of the physiological processes involved in performing a voluntary action can be challenged and thereby contribute to the development of fatigue. This could indicate that the CMJ performance is independent of perceived fatigue, which explains the weak correlation between the CMJ variables and the ROF and PRS scores

(Enoka & Duchateau, 2016). Table 10 shows that the BW of the athletes decreased significantly post workout compared to pre workout. This decrease in weight is due to water loss. The workout was performed on a humid morning, which means the athletes sweat a lot. The athletes might have been dehydrated, which causes them to perceive more fatigued than they are. A study performed by Ganio et al. (2011) found that mild dehydration in men increases perceived fatigue. A systemic review paper concluded that hydration status affects fatigue in endurance sport including perceived fatigue (Pellicer-Caller et al., 2023). Another study performed in trained male combat sport athletes found that acute dehydration impairs muscular strength-endurance and increases fatigue perception without changes in neuromuscular function (Barley et al., 2018). This could be a possible explanation for only finding moderate correlations between the perceived fatigue (scales) and neuromuscular fatigue (CMJs). Another explanation for the moderate and non-significant correlations could be that the athletes required a longer warm up duration or alternative warm up format. Previous research performed by Burkett et al. (2016) and Nicolas et al. (2008) showed that warm-ups increase countermovement jump performance. However, a typical warm-up for the college cross-country athletes is a 3-mile run at 8 minute per mile pace. The workout was a 3.5-5-mile tempo at threshold pace, which is ~5:45 pace for the females and ~5:05 pace for the males. This increased CMJ performance after the 3-4 mile run at 8-minute pace may support that despite performing 10 body weight squats prior to the CMJ testing, the athletes were not sufficiently warmed-up. Potentially the CMJ jumps could be performed prior to the team warm up, after the warm-up and post tempo session in future investigations.

Limitations

Several limitations exist in the current study. Firstly, the athletes just woke up when they started their morning workout. Some of them did not eat breakfast yet. As a warm-up for the CMJs, individuals did 10 body weight squats, however this was done to provide a standardized warm up without increasing the training mileage. This might not have been enough to completely warm-up their body, which might have affected the results (Filliard et al., 2010; Holt & Lambourne, 2008). Secondly, all data collection occurred outside of a controlled environment. The runners were instructed to do their post-workout jumps five minutes after they finished their cooldown which is within the time frame of previous papers (Esformes et al., 2010). In addition, the runners all filled out the scales when they could hear the results from their teammates, this might have affected their own responses. However, the scales were previously explained to them prior to the training session. Another limitation of the current study was that the objective was a CMJ, which is not close to the movement of running. There may be changes in the muscles that were not detected whereas a different exercise such as lunges or running over a force plate might have shown more results. However, CMJs are more reliable and valid (Goran et al., 2004). Finally, the current study did not include a control group that jumped at the same time as the athletes but did not do a workout. A control group would have made the evidence stronger that the workout affected the jumps.

Conclusion

Countermovement jumps are an indicator of neuromuscular fatigue (Claudino et al., 2017) in multiple sports. Overtraining is a common cause of injury in distance runners, therefor load monitoring in distance athletes is of value. Trained endurance athletes can maintain their strength and run while they are fatigued which supports the fact that increase in performance is partly due to neuromuscular adaptions. This also shows that monitoring power in endurance athletes is of value (García-Pinillos et al., 2015). However, the most optimized testing remains unclear and warrants additional investigations. The aim of this study was to determine if CMJ performance in collegiate cross-country athletes has a relationship to neuromuscular fatigue. Significant increases post workout compared to before the workout were found in jump height, power, single leg jumps height and single leg power. These results indicate that the athletes were less fatigued after the workout, however an increase in perceived rate of fatigue and a decrease in perceived recovery was found. Potentially this perceptual fatigue was more aerobic as opposed to neuromuscular. Additionally, no significant strong correlations between the perceived fatigue and CMJ performances was found. These results indicate that there is no relationship between the CMJs and neuromuscular fatigue within the current paradigm. In the future it would be worthwhile to examine CMJ performance before the warm-up, after the warm-up and post workout at various time intervals. This would potentially give practitioners additional guidelines when testing within this population should be completed.

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VITA

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While at the University of Mississippi Kristel ran for the Track and Field and Cross-Country team and was voted student-athlete of the month in April 2023. She received multiple all-academic awards while she attended the University of Mississippi. Her highlight was winning the gold medal in the 2023 SEC Track and Field Championships in her event, the steeplechase.