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The Influence of Fatiguing Exercise on Power Output

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THE INFLUENCE OF FATIGUING EXERCISE ON POWER OUTPUT

By

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The Influence of Fatiguing Exercise on Power Output

Abstract

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Physical fatigue impairs performance during high power, short duration activities. As technological developments permit new methods of measuring this effect, it is important to validate existing paradigms. The purpose was to determine if kinetic measurements from vertical jump (VJ) tests are influenced by fatigue based on explosive power outputs. A sample of athletes (9 men, 26 women) from a Division I NCAA sports program completed testing. To establish baseline VJ kinetics, athletes performed a controlled warm-up and then completed six jumps using Sparta Science technology, each separated by 15s rest. Sparta software computed three force outputs: Load, Explode and Drive. After baseline VJ calculation, performed an anaerobic fatigue protocol on a cycle ergometer: three 15s sprints separated by 10s rest. Max and average power were recorded from the cycle trials. Subjects then repeated the VJ protocol. This pattern was repeated until six sets of VJ were recorded. Repeated measures ANOVA tested differences between successive VJ performances. Male athletes were 20.8 ± 1.5years old, weighed 175.8 ± 14.0lbs, had a baseline VJ of 46.9 ± 3.6cm, Load of 53.6 ± 13.3, Explode of 49.4 ± 6.6, and Drive of 49.4 ± 11.9. Female athletes were 20.2 ± 1.2years old, weighed 142.3 ± 13.2lbs, had a baseline VJ of 32.7 ± 4.3cm, Load of 49.8 ± 46.1, Explode of 40.7 ± 8.0, and Drive of 63.1 ± 49.7. Differences between sex were weight ($p<0.001$), VJ ($p<0.001$), and

Explode ($p=0.006$). ANOVA found VJ height to decrease between baseline and trial 2 ($p<0.001$), no difference between sex ($p=0.210$); and between trials 2 and 6 VJ height was consistent ($p>0.400$). Load was not affected by the fatigue protocol across the total sample ($p=0.418$) or by sex ($p=0.239$). Explode was not affected by fatigue across the sample ($p=0.233$) or by sex ($p=0.406$). Drive was affected by fatigue ($p=0.040$), decreasing in successive trials; no interaction with sex ($p=0.742$). VJ is more sensitive to fatigue than Sparta's force plate calculations. An initial fatiguing insult was sufficient to compromise performance, whereas accumulated fatigue didn't have an additive effect. Drive was the only force variable that was affected by fatigue.

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Chapter 1: Introduction

One hundred and fifty years ago, the Vertical Jump Test was used to measure an individual's athleticism based on the maximum height that they were able to perform. During the last 20 years, Sparta Sport Performance has advanced this idea and developed a software to evaluate the vertical jump's ground reaction forces to quantifiably measure athletic power. The physiology to perform the vertical jump requires strength and mobility through the hips, which drive the athlete's speed and force. One main goal for head coaches, strength coaches, and athletic trainers is to safely strategize training so that athletes can perform at the highest-level during competition. When using this software for an elite program, trainers now not only have the ability to see how fit or strong an athlete is, but more importantly they can detect muscular imbalances for injury prevention. With years of data collection, Sparta Science has refined their exercise prescription to help trainers and coaches create an individualized exercise plan for each athlete so that they can perform to the best of their ability.

The athletics department at the University of the Pacific utilizes Sparta Science as a quantitative tool in tracking athlete wellness. Every year, all athletes perform a baseline Sparta assessment so that trainers and coaches are able to create healthier, stronger, and more connected athletes. Strength trainers can alter training sessions and provide feedback to the coaching and athletic training staff based on the results. The Vertical Jump Test measures the ability to display power, explosive strength, and the ability to use that strength in a specific direction. With explosive movements, comes overtraining due to fatigue. It's inevitable to feel fatigue during intense training and understanding its effect on the human body is important, especially for high-level competition.

In 2002, A.L. Rodacki and his colleagues N.E. Fowler and S.J. Bennett conducted a study that demonstrated how electrode stimulated fatigue in the knee extensor muscles could decrease max height activation, since neural control is no longer optimal for muscle strength. (Rodacki et al., 2002) Other studies involving cycling, sprinting, lifting, and other repeated jumping exercise provide evidence that some compensatory mechanisms are used to counterbalance the loss of the muscle force-generating properties due to fatigue. (Hautier et al., 2000; Heiser et al., 1996; Pinniger et al., 2000; Bonnard et al., 1994) This is done to avoid deterioration of the performance when properties of the musculoskeletal system are changed, inducing a reorganization of the movement structure and a new coordination pattern may appear. One other cycling fatigue study discovered that with a series of sprints, muscles steadily activate and transfer energy from agonist to antagonist muscles despite loss of force. (Hautier et al., 2000) In 2011, Kirby et al. found peak force and peak power were both positively related to vertical jump, with peak power being the single best predictor of jump height. Previous results of kinematic and EMG studies show that countermovement jump timing, sequence, and amplitude of the muscle activation and joint movements are similar. (Jacobs & van Ingen Schenau, 1992) Countermovement is when muscles eccentrically stretch and quickly shorten to accelerate the body in the opposite direction and achieve the reverse desirable action. (Kraemer & Newton, 1994) To our knowledge, evidence on jumping kinetics with acute fatigue performed on a friction-loaded cycle ergometer is limited in DI collegiate athletes, with even less research using SpartaTrac software. (Rodacki et al., 2002) This study will be able to fill this gap in by examining velocity and power losses during repeated sprints on an assault bike.

The objectives of the present investigation are: 1) Determine if a repeated 15s cycle sprint to 10s rest interval adequately applies anaerobic threshold in DI athletes, 2) Analyze how

Movement Signatures respond to anaerobic activity, 3) Investigate how levels of power output affects the athlete's jump height, and 4) Determine the correlation between vertical jump performance and recovery to peak performance. The potential validation of a simple procedure of the vertical jump as a predictor of athlete fatigue and recovery time is the primary benefit. Coaches and trainers could then use this test to track athlete wellness and adjust conditioning routines accordingly. This could potentially reduce future injury risk and improve peak performance of athletes at our institution and at other similar institutions.

Hypothesis

1. The subject's maximum jump height, eccentric and concentric force values, and maximum power output seen on the ergometer should decline with fatigue because they will not be able to sustain power.
2. Peak power will decline over time from the change in neural sequencing and/or the change in the muscle's functional capacity to produce force.
3. Age and athletic position should be significant in the results
4. Recovery time evaluations may be difficult to assess in such a short study.

Delimitations

1. Subjects were delimited to University of the Pacific athletes ages 17-22 who are currently apart of their DI NCAA Sport Program.
2. The study was delimited to a series of background questions, a warm up, a Wingate Interval Protocol, and a Force Plate Assessment using Sparta Science software on Kistler Force Plate hardware.

3. The variables measured in the Sparta Scan were delimited to effort, ability, technique and auditory cues to assess and diagnose ground reaction forces to power production.
4. The variables measured on the cycling ergometer were delimited to resiliency, mental toughness, persistence, ability and ego.

Limitations

The study was limited by the following:

1. The possibility of athletes not answering the questionnaires truthfully.
2. The amount of time to collect data and incorporate a wider data pool.
3. The ability of the researcher to explain how fatigue levels don't significantly affect or alter power production and output.
4. The possibility of poor jumping technique or small injury that affect results of the vertical jump force plate measurements.
5. The possibility that athletes were already fatigued before the fatigue study, or were holding back from maximal effort to sustain their energy for competition, altering results to assess maximal fatigue levels and maximal power production change
6. The ability of the researcher to document max power output on every single sprint bout and import those numerical values exactly into the electronic database correctly.

Threats to Validify

1. How vertical eccentric to concentric loading and force transfer is a valid measure of max power production and reliable measure of physical strength and weaknesses.
2. How Sparta Science honestly proclaims that their software can prevent injury.

Chapter 2: Review of Literature

The Vertical Jump and Power Output

Dudley Sargent (1849-1924) created the Sargent Test 150 years ago (now known as the Vertical Jump Test) to measure one's athleticism based on the height of their vertical jump. After graduating from Yale Medical School in 1878, he was appointed Assistant Professor at the Harvard Gymnasium where he designed different training techniques and exercises to measure and test his student's fitness. The test was originally performed with tape, chalk, and a wall. Students would mark their fingers with the chalk, jump and tap a wall that contained tape marks of different jump heights. Now to document vertical jump height, we use advanced tools like the Vertec or a force plate. The Vertec is a plastic and metal apparatus similar to a ruler, whereas the force plate is more electronically advanced. A Vertec looks similar to a comb; it contains horizontal plastic pieces in red, white or blue at the top of a vertical metal pole to mark feet, inches and half inches. Students stand underneath the apparatus, jump and tap the colored plastic pieces to mark their jump height. The force plate is the most accurate equipment in the market to assess jump height, but it is also the most expensive and therefore more uncommon method. Not only does the force plate discover jump height, it also evaluates athletic wellness based on the ground reaction forces displaced into the plate. It has the technology to access force variables correlated to balance, strength and power, and is even said to aid in injury prevention based on muscular imbalances.

The Vertical Jump is one of the most explosive movements performed in sports and can be a huge predictor in athletic success. It involves raising one's center of mass higher in the vertical plane solely with the use of one's own muscles; it's a measure of how high an individual or athlete can elevate off the ground (jump) from a standstill. Basketball, field events in Track and Field, and Volleyball are three prominent examples where higher jumping can lead to higher chance in winning percentage. Jumping ability is an indicator of athletic ability in terms of speed, explosive power, leg strength and hip mobility. (Rodriguez-Rosell et al.) The height that an athlete can jump is mainly determined genetically by the distribution of fast-twitch vs. slow-twitch fibers in the leg muscles, however this can also be partially mutable through resistance exercise training. With fast-twitch muscle fibers, the brain will quickly transmit impulses to muscle to create fast contractions for speed. An athlete with a greater distribution of fast-twitch muscle fibers will most likely be able to jump higher than an athlete with more slow-twitch fibers. Jumping, bounding and hopping exercises in plyometric training will not only enhance vertical jump height, but it has also shown to enhance linear speed and explosive direction change. Plyometric training should be done with proper technique at the highest intensity, and with fatigue onset it must be supervised and planned with caution. Progressions and proper rest intervals are important to reduce the risk of injury and limit stress on the target muscle groups. By concentrating on jumping mechanics, we improve our body awareness, overall motor control, leg strength, and flexibility. Research into plyometric jumps found vertical jumps to be among the highest in terms of muscle recruitment, power output, and ground reaction force produced. (Beneka et al.) Coaches can look at a player’s vertical jump immediately to tell how explosive they are, which correlates to competition speed, agility, quickness, and explosive power. It can also be used to assess state of recovery prior to a weight-training, speed or practice sessions. Over-training the nervous system by performing an excessive volume of heavy weight or high-speed training causes fatigue, and this should show in your vertical jump height results. More recovery or altering training volume and intensity can be done to lead to peak performance.

Effects of Fatigue on Power Output

Performing intensive motor tasks for long periods of time creates fatigue, which is generally defined as a decline in a person's ability to exert force. (Lorist et al.) Fatigue can be caused by many different mechanisms specific to the task being performed; either from the accumulation of metabolites within fibers (metabolic fatigue), or by the generation of an inadequate motor command in the motor cortex (neural fatigue). A muscle begins to fatigue when its maximal force or power capacity starts to decline, causing performance to wane. Anita Beelen and A.J. Sargeant examined the effect of fatigue on muscle power generated at different pedaling rates during cycling. Results showed that the effect of fatiguing exercise on subsequent power output is dependent on the pedaling rate at which power output is generated. They discovered "no significant reductions in maximal peak power at the lower velocities of 60 and 75 rpm, whereas at the higher velocities, 90, 105, and 120 rpm, there were significant reductions in power output ranging from 23 to 28%." (Beelen & Sargent) Power reduction due to fatigue therefore is correlated with the amount of effort and force you produce, and the faster or more effort you give, the faster you will fatigue and decline in performance.

The muscular system is controlled though the nervous system, although some muscles like the cardiac muscle can be innervated automatically. Muscle is a contractile tissue that is anchored by tendons to bone to produce force and cause motion, either with locomotion or movement within internal organs. Muscle is composed of muscle cells, known as muscle fibers, and within these cells are myofibrils that contain sarcomeres composed of actin and myosin. Muscle cells are bound together by perimysium into bundles called fascicles, which are then grouped together to form a muscle line by epimysium. Muscle spindles are distributed throughout the muscles and provide sensory feedback information to the central nervous system.

Electrical impulses from the brain signal muscles cells to contract through the release of calcium by the sarcoplasmic reticulum. Nerves are responsible for controlling the amount, sequence and intensity of muscle contraction. Skeletal muscle and be divided into either type I or type II fibers. Type I fibers are slow oxidative (slow twitch) or red muscle that is dense with capillaries and rich in mitochondria and myoglobin to carry more oxygen and sustain aerobic activity. Type II fast twitch muscle can be subdivided into three categories, in order of increasing contractile speed. Type IIa is aerobic and rich in mitochondria with red capillaries. Type IIx is less dense in mitochondria and myoglobin and is the fastest muscle type, which can contract more quickly and greater in short anaerobic bursts before pain or fatigue occurs. Type IIb is anaerobic, glycolytic white muscle that is the densest in mitochondria and myoglobin.

There are approximately 640 skeletal muscles in the human body, and contrary to popular belief, the number of muscle fibers cannot be increased through exercise, but the cells can get bigger. Myofibrils have a limited capacity for growth through hypertrophy and will split if subject to increased demand. All skeletal muscles are stimulated by nervous impulses that release acetylcholine at the neuromuscular junction, creating action potentials along the cell membrane. (Human Physiology/The Muscular System) In extremely powerful contractions, enervation (nervous fatigue) can limit the muscle's ability to interpret the nerve's signal and generate force. In strength training, it is part of the process to increase the nerve's ability to generate sustained, high frequency signals. Once the nerve is generating maximum contractions, the muscle will reach its physiological limit. Muscular strength thus is increased through myofibrillar or sarcoplasmic hypertrophy, in which eventually metabolic fatigue becomes the factor limiting contractile force. (Dee)

Metabolic fatigue is defined as the reduction in contractile force due to the direct or indirect effects of substrate shortage in the muscle, or accumulation of metabolites in the muscle that interfere with calcium release to stimulate the contraction. Substrates such as ATP, glycogen, and phosphocreatine power muscular contraction. The sliding filament theory, or also known as cross-bridge cycling, explains how muscles contract. In short, ATP binds to the head of thick myosin filaments of a muscle fiber, which slides past and interlocks with thin actin filaments to contract a muscle. Phosphocreatine stores energy so ATP can be quickly regenerated in muscle cells and sustain a 5-7sec contraction. Glycogen is stored glucose, which replenishes exhausted creatine and lactic acid is produced as a byproduct. Waste products (metabolites) including chloride, potassium, lactic acid, ADP, magnesium, reactive oxygen species, and inorganic phosphates, interfere with the sarcoplasmic reticulum to release calcium, and desensitizes actin and myosin to contract. High amounts of potassium will cause cramping because as it builds up in the T-tubule, it shifts the membrane’s action potential. In the past, lactic acid was believed to cause soreness or limit muscle contraction, however now it is used as a measure of endurance training effectiveness with the VO2 max. (Sahlin)

When athletes fail to recover from training, they become progressively fatigued and suffer from prolonged underperformance, known as overtraining syndrome, burnout, staleness or chronic fatigue. All athletes must train hard to improve and should follow a designed periodization to allow time for recovery with their progressive overload. There can be initial changes in mood that show vigor, tension, depression, anger, and/or confusion. Glycogen stores decline, resting heart rate rises, testosterone lowers, and cortisol rises. (Budgett) Several methods have been used to quantify training load, including questionnaires and technology such as perceived exertion scores and heart rate monitors. To date, no single physiological marker has been identified that can measure the fitness and fatigue response to exercise or accurately predict performance. (Borresen & Lambert)

Acute neuromuscular fatigue and its recovery with maximal strength loading and explosive strength loading were examined in Linnamo's study amongst men and women. It was concluded that heavy resistance loading reduced electrical activity in the muscles as blood lactate accumulated, and explosive type loading especially in men lead to a quicker fatigue. Anaerobic threshold defines the level of intensity during exercise at which the aerobic system can no longer keep up with the body's energy demand. When the body's energy demand is high, muscle contraction cannot be maintained, and speed, force and therefore power changes. A bike test implementing work to rest intervals to fatigue the subject's muscles before a vertical jump test was easy and time effective. We wanted to see how fatigue affects levels of power—what or how it occurred, when and why, as well as validate the diagnostic procedure that the company claims aids in injury prevention or rehabilitation.

Chapter 3: Methodology

Experimental Approach to the Problem

A cross-sectional experimental design investigated the influence of fatigue on countermovement jump force-time characteristics in a randomized group of elite college athletes. Thirty-five male (n = 9) and female (n = 26) skilled athletes (soccer, baseball, swimming, and track & field) reported to the Pacific Athletics Training Facility for a single 30-min testing procedure. Data was collected in November and April during the off-season to avoid limitations in competition schedules. Subjects were informed with all test procedures 2 weeks before the experiment date. Each subject was asked to properly prepare for the assessment (i.e., no strenuous training at least 24 hours prior to the test, wearing athletic attire, and adequate amounts of food, water, and sleep), and was scheduled individually to ensure the integrity of data collection. Anthropometric measurements (height, BMI) and other variables were first gathered. A standardized 4-min dynamic warm-up of lower-body stretches, mobility exercises, and submaximal VJs prepared the subjects for maximal-effort assessment. A 2-min rest period was given after the warm up and a CMJ baseline trial was performed before commencement of jump testing. The testing protocol involved an assault bike, a force plate and a laptop with data analysis software. No technique was instructed during the experiment. All subjects were well conditioned and familiar with the exercises as they were both performed regularly during their sports training programs.

Subjects

Nine male (age: 20.8 ± 1.5 y; body mass: 1.84 ± 0.08 kg) and 26 female (age: 20.2 ± 1.2 y; body mass: 1.71 ± 0.05 kg) NCAA Division I student-athletes from the University of the

Pacific were recruited by word of mouth. They were physically active, cleared from any limiting medical conditions, and have previous experience with the force plate equipment and assault bike. A majority of the volunteers played the sport of soccer, yet athletes from other sports teams were present. Descriptive statistics of the participants are listed in Table 1. Each participant signed a written informed consent statement before the investigation after receiving a verbal and written explanation of the experiment in accordance with standards established by the University Human Subject Review Board. In addition, written permission was also collected from the subject's head coach at the expense of possible injury. Risks and benefits were shared to all those that may be affected by the investigation. Therefore, the research ethics committee of the University of the Pacific approved the procedure of this study. The data collection process was completed free of injury.

Table 1: Descriptive Statistics by Sport (mean ± SD). *

		Age (y)		Height (m)		Body Mass (kg)		BMI	
	N	Males	Females	Males	Females	Males	Females	Males	Females
Soccer	31	20.6 ± 1.6	20 ± 1.1	1.82 ± 0.05	1.71 ± 0.05	77.43 ± 5.02	64.15 ± 5.55	23.4 ± 0.95	22.0 ± 1.48
Baseball	1	21 ± 0	NA	1.83 ± 0	NA	88.45 ± 0	NA	26.4 ± 0	NA
Swimming	1	22 ± 0	NA	2.01 ± 0	NA	87.23 ± 0	NA	21.7 ± 0	NA
Track & Field	2	NA	20 ± 2.8	NA	1.66 ± 0.01	NA	69.18 ± 11.61	NA	25.2 ± 4.53

*NA, not available

Procedures

First each participant verbally answered a few questions in regards to what sport and position they played, what their age (y) was, whether they have any injuries, what their perceived diet was over the past week on a scale of 1-10 (1=poor), and the amount of sleep (hrs) they had the night before. Their height (m) and BMI were determined. A Polar heart rate monitor was worn to gage pre- and post-heart rate (bpm) values. Then the subjects underwent a 4-min warm up, including various bodyweight lunges, lower-body musculature stretches, and low level plyometrics, similar to a typical warm-up during normal training, to control potential variables, avoid injury and improve reliability. Two minutes after the warm up, the athlete was then instructed to perform 6 countermovement jumps, separated by 15s of rest, for baseline purposes. Five Cycle-Jump sets were then performed as part of the testing protocol, however athletes were permitted with withdraw early if dizzy, nauseous or in pain. Each cycle set was executed on a mechanically braked bicycle ergometer at a constant resistance and conveyed to perform fatigue, as three 15s sprint to 10s rest intervals were implemented. Each jump set again included 6 individual jumps, separated by 15s of rest. Figure 1 illustrates the study design. No restriction was made on upper extremity or trunk motion during the trials and the subjects were encouraged to perform the task as naturally as possible.

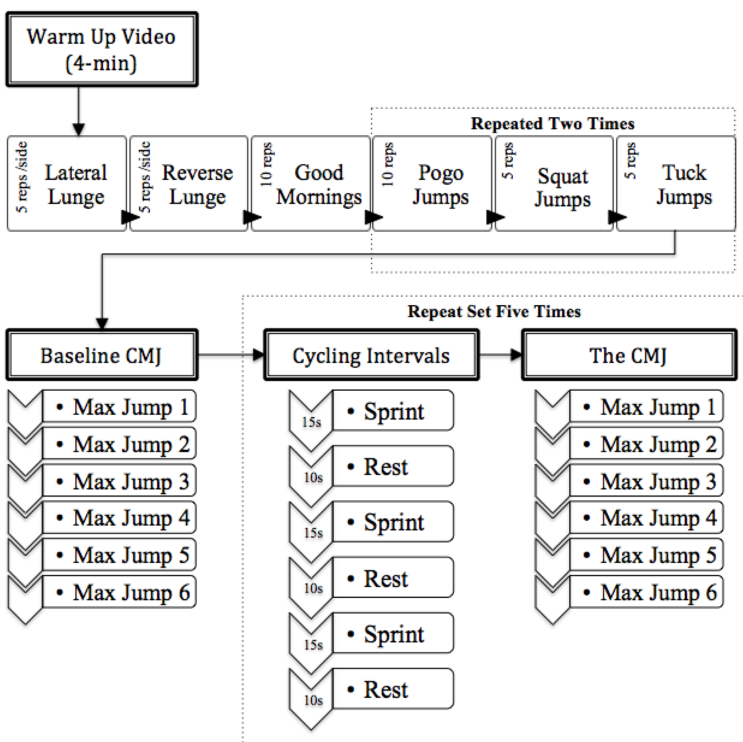

Figure 1: Study Design

$$\textbf{\textit{JUMP HEIGHT (m)}} = \frac{K-1}{K}\left(1 - \frac{\sum_{i=1}^{K}\sigma^2 x_i}{\sigma_Y^2}\right) = 0.920$$

$$\textbf{\textit{LOAD} (}\overline{\textbf{\textit{ECC}}}\textbf{ force \textit{in N/s})} = \frac{K-1}{K}\left(1 - \frac{\sum_{i=1}^{K}\sigma^2 x_i}{\sigma_Y^2}\right) = 0.984$$

$$\textbf{\textit{EXPLODE} (}\overline{\textbf{\textit{CON}}}\textbf{ force in \textit{N/kg})} = \frac{K-1}{K}\left(1 - \frac{\sum_{i=1}^{K}\sigma^2 x_i}{\sigma_Y^2}\right) = 0.991$$

$$\textbf{\textit{DRIVE (CON} impulse in \textit{Ns/kg})} = \frac{K-1}{K}\left(1 - \frac{\sum_{i=1}^{K}\sigma^2 x_i}{\sigma_Y^2}\right) = 0.858$$

Figure 2: Formula for each *Movement Signature* variable

Data acquisition and analysis of the countermovement jump. The CMJ data collection system included a commercial piezoelectric 0.3m × 0.5m force plate (9260AA; Kistler Instruments, Winterthur, Switzerland) connected to a HP laptop with SpartaTrac software (SpartaTrac; SPARTA Performance Science, Menlo Park, CA, USA) for data interpretation. Subjects began on the platform in a bilateral stationary stance, and then were signaled to jump as high as possible with arm swing at a self-selected depth. (Nibali et al., 2015) Kinematic data sampling at 1000Hz were recorded during the six-consecutive unloaded CMJs (i.e. body mass only). The raw data including jump height (m), body mass (kg) and force-time measurements for each of the six jumps were recorded, exported and saved to a customized Microsoft Excel spreadsheet (version 14.6.2, Microsoft Corp., Santa Rosa, CA, USA). SpartaTrac software averaged the 3 highest CMJs to improve reliability, explain 90% of the variability, and define a concise basic understanding of the results. Formulas of the variables are depicted in Figure 2 and were described as a different form of nomenclature to classify and quantify identifiable qualities after years of force-time curves studies. SpartaTrac's calculations include similar significant qualities from previous investigators that have reported strong correlations between jump height with eccentric rate of force development (Nibali et al., 2015), relative net vertical impulse (Kirby et al., 2011), and peak force. [Dowling et al., 1993; Nuzzo et al., 2008; Peterson et al., 2006; Rousanoglou et al., 2008; Yamauchi et al., 2007) The vertical jump height was determined using concepts from Newton's Second Law of Motion, the Law of Conservation of Energy, and the Impulse-Momentum Theorem right after takeoff during the displacement of the subject's center of mass. (Linthorne, 2001) Momentum is gained during the squatting phase of the CMJ. At takeoff, platform sensors pick up impulse from the magnitude and duration of kinetic force variables, and with respect to gravity and mass held constant, we were able to determine jump height without any landing or timing errors. Jump height was also strongly correlated with the ground reaction force (GRF), the force exerted by the ground on a body it's in contact with. All subjects received jump height results in centimeters on a television screen immediately after each jump and were encouraged to continue to perform their best during mental and physical fatigue. (Rodacki et al., 2001) Neuromuscular fatigue is defined as the decreased capacity to produce force, thus during exercise, GRF is decreased because the body cannot maintain a constant high level of power. The force plate can monitor fatigue, especially when the Signature displays a decrease in Load, or rate of force production from anterior muscle power. Explode justifies muscle mobility during direction change when force is transferred from eccentric to concentric movements. Drive classifies the rate of force production from both posterior muscle power and mobility. One study tested Explode and Drive as subjects sprinted and pushed off a platform to transmit an impulse from the direction change, exposing that women produce more force and have less hip flexion during fatigue. (Srinivasan et al., 2016) Thus as female athletes fatigue, Drive should increase. Load, Explode and Drive variables within a Movement Signature are illustrated in the bar graph shown in Figure 3. SpartaTrac aims to increase performance and reduce injury by keeping all variables in balance within a t score or value of 15 through validated assessments and evidenced-based prescriptions. Different neuromuscular solutions can be classified into Linear, Rotational or Lateral movement patterns.

Jan 2016	LOAD	EXPLODE	DRIVE
Running Back	66	72	45
Wide Receiver	72	74	43
Quarterback	50	53	48
Defensive Back	62	67	44

Jul 2016	LOAD	EXPLODE	DRIVE
Running Back	71 *(+5)*	72 *(0)*	56 **(+11)**
Wide Receiver	73 *(+1)*	79 *(+5)*	51 **(+8)**
Quarterback	56 *(+6)*	54 *(+1)*	55 **(+7)**
Defensive Back	60 *(-2)*	65 *(-2)*	53 **(+9)**

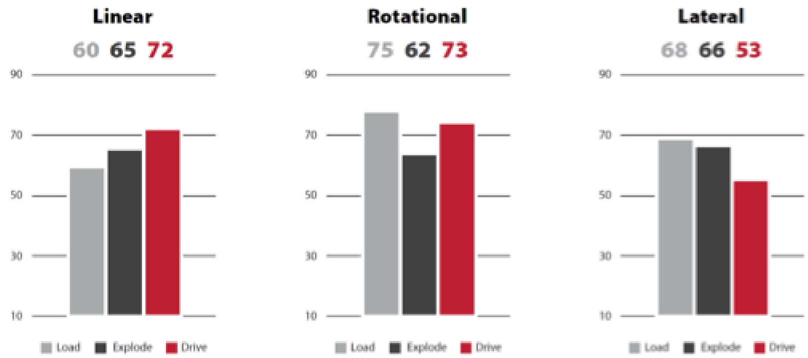

Figure 3: Movement Signatures based on sport position or movement patterns

Linear athletes are hyper mobile in the hips and knees and struggle to produce force to stop momentum, thus split squats can be used to strengthen and stiffen the abdomen for more control. Rotational athletes relax during force production to generate strength, which has robust effects on the lower back, therefore deadlifts can be used to enhance the lower back's ability to brace and transfer force. Lateral athletes are quick, agile and energy efficient, but stop momentum too early and brace deceleration poorly, thus front squats can be used to strengthen posterior muscles in the gluteus or hamstrings to reduce muscle pain. Extreme low Drive or high Explode shows very good reactive strength yet stiffness and poor muscle compliance. Extremely high Drive or low Load depicts poor strength and posture, also resulting in trunk or knee strains. Athletes who are utilizing different neuromuscular solutions, or have extreme imbalances, can be at risk of injury. The athlete's baseline Movement Signature should be roughly maintained during training since it was developed specific to their position played in their sport. The baseline athlete's neuromuscular movement pattern can also be used to compare internal efforts when sleep, stress, soreness, and fatigue are present. A fatigued athletes' Signature could continue to have the same level of output due to compensation, by going about achieving that performance in a different way. The Signature doesn't change with muscle fatigue as much as with neurological stress. If a Signature begins to shift dramatically from baseline, training volume should be reduced, not training type. Average eccentric rate of force development (Load) was determined between the minimum and maximum force. Average concentric force was determined as the average force achieved during the concentric phase and expressed relative to body mass (Explode). Concentric impulse was calculated as the integral of the GRF over the duration of the concentric phase and is expressed relative to body mass (Drive). Peak Power was listed in numerical order, (1-5, low-high) from the results of a study that measured jump height with soccer players.

Data acquisition and analysis of cycling intervals. Peak power (W) was observed and recorded from the assault bike's ergometer during each 15s cycle sprint. Lactate threshold was assumed when the lowest power output reached 30% of their max. (Thomas et al., 2019; Stanula et al., 2013) A 15s high exercise intensity and volume sprint involves mainly anaerobic metabolism. Literature reports goalkeepers have the highest anaerobic power, while midfielders present the lowest, (Stølen et al., 2005; Adhikari et al., 1993) however my results show forwards present the lowest. Based on a study involving sprinting and elite soccer players, we ranked each athlete by the power output based on those position outcomes (i.e., track and field sprinters, pitchers, or swimming sprinters were labeled as the most powerful with 5, goalkeepers with 4, forwards with 3, midfielders with 2, and defenders with 1). (Chiu et al., 2003) This study shows that central defenders sprint the least, followed by central midfielders, and then forwards. To keep the study consistent, we labeled each position with a numerical power description. All subjects acted fatigued upon commencement of the third round of each interval. The Functional Threshold Power test uses perceived exertion to understand limits on the assault bike. Concepts involving lactate threshold and anaerobic capacity measurements were extracted from Coggan's Table 3.1, stating that active recovery was the least strenuous (<55% of Peak Power, <68% Heart Rate), endurance 56-75%PP 69-83%HR, tempo 76-90%PP 84-94%HR, lactate threshold 91-105%PP 95-105%HR, vo2 max 106-120%PP >106%HR, and anaerobic capacity 121-150%PP NA HR%). (Allen & Coggan, 2012) This study shows that their functional threshold percentage of heart rate could not be determined during anaerobic capacity, meaning the heart rate monitors were not going to help with determining anaerobic performance, however post heart rate was monitored for the subject's safety and documented for further exploration if needed. Each subject reached lactate threshold, and this value was calculated using Coggan's Power Training Levels system. After collecting all data, the mean Watts was calculated and multiplied by 95% to receive the lactate threshold value based on the functional threshold power. If this number was reached, the subject was prompted to stop the study, as it might negatively hinder their performance during practice in the following days.

Statistical Analysis

The statistical procedures were conducted using IBM Statistical Package for the Social Sciences (SPSS) Statistics software (25.0 for Mac, SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to verify that the basic assumption of normality of the dependent variable was met. Those values for anthropometric data are reported in APPENDIX A. A paired samples T-Test, was used to analyze and compare each of the force variables performed per 6 jumps. The number closing the variable's name represented the set that they were on when they received their Load, Explode, or Drive score. The mean and standard deviation were calculated for each variable. A multiple linear regression model between sex and sport position was made. Additional statistical analyses were made using a Bivariate Correlations Table, shown in APPENDIX B. Correlations between position played, vertical jump variables, change in jump height, and power output was used to present variance of one of the outcomes shown in Figure 5, using a Repeated Measures ANOVA with a post hoc Bonferroni comparison. The ANOVA shows that the initial jump is significantly different than the jumps in the study, showing little variance and thus a consistency thereafter. Thus, this data only focuses on the change from jump height 1 to jump height 2. The Greenhouse-Geisser model in Mauchly's Test of Sphericity tells us that the $p<0.0001$ proves there's a difference between each jump for a significant reason.

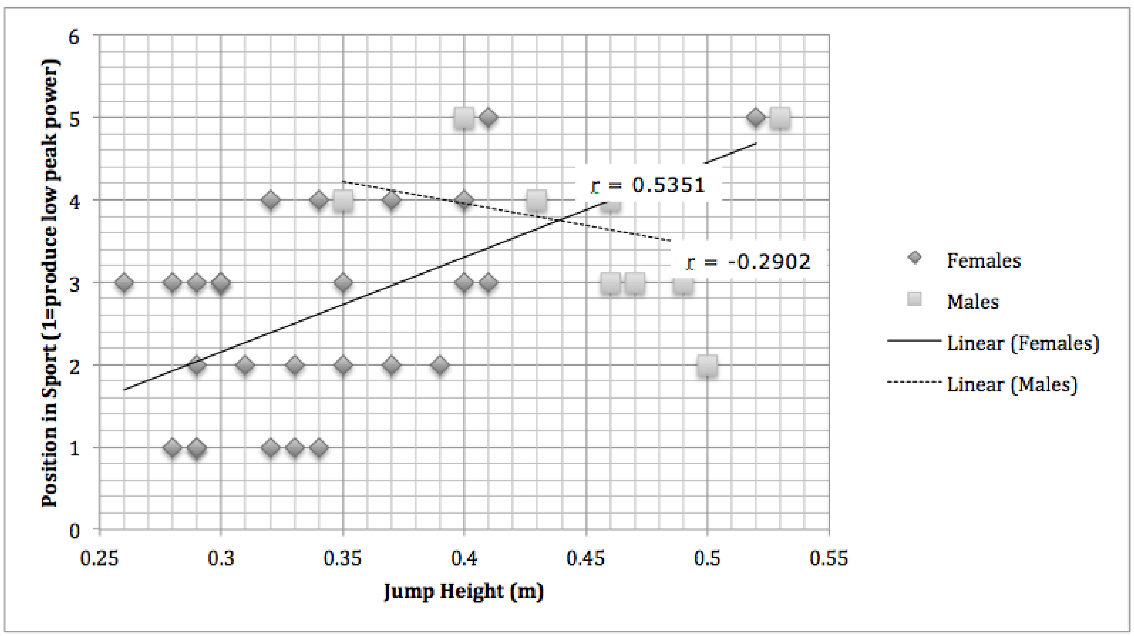

Figure 4: Multiple Linear Regression Model between Sex and Sport Position

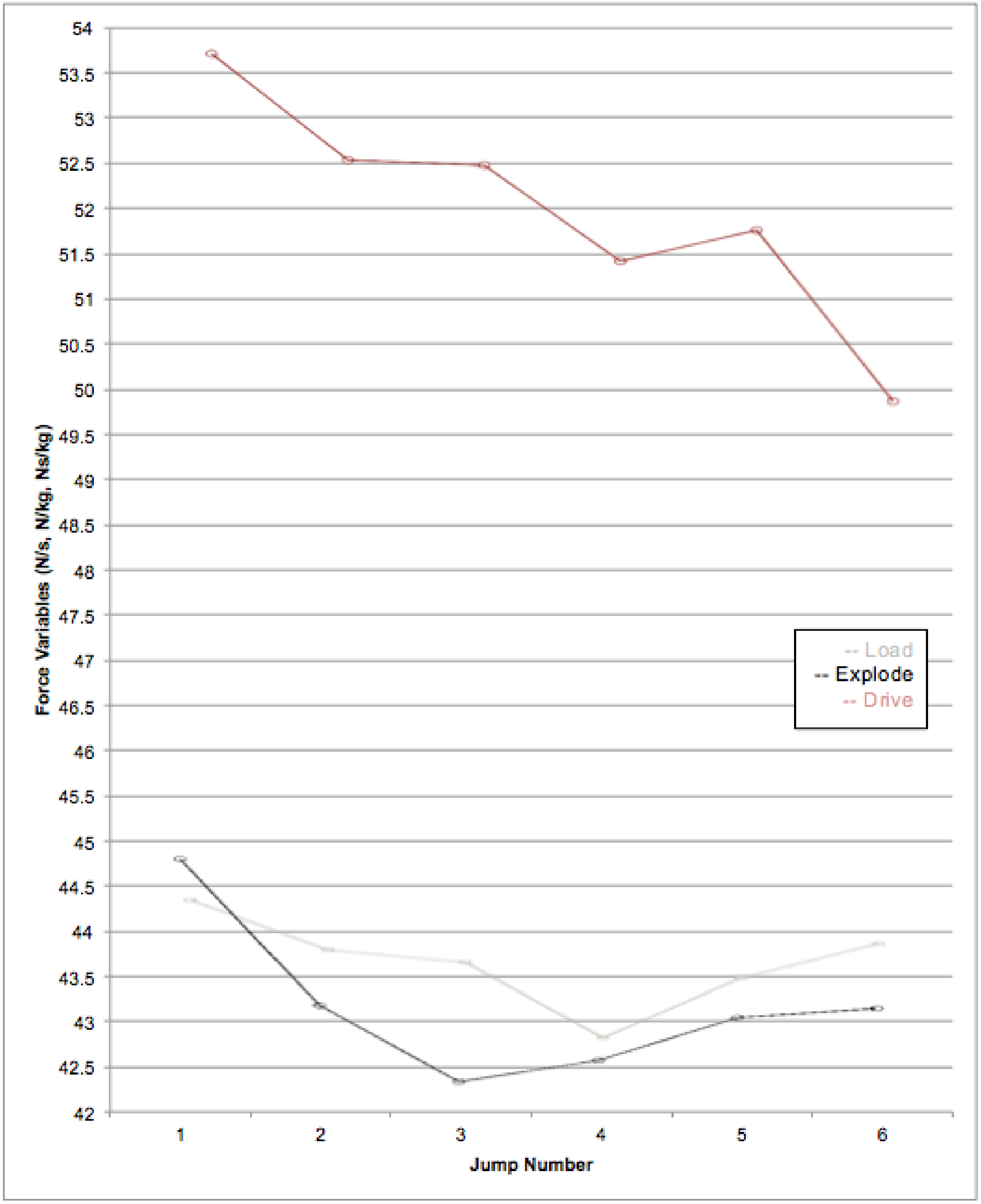

Figure 5: Estimated Marginal Means for Load, Explode and Drive

Chapter 4: Draft of Manuscript

Title

The Influence of Fatiguing Exercise on Power Output

Abstract

Background. Physical fatigue impairs performance during high power, short duration activities. As technological developments permit new methods of measuring this effect, it is important to validate existing paradigms. **Purpose.** To determine if kinetic measurements from vertical jump (VJ) tests are influenced by fatigue based on explosive power outputs. **Methods.** A sample of athletes (9 men, 26 women) from a Division I NCAA sports program completed testing. To establish baseline VJ kinetics, athletes performed a controlled warm-up and then completed 6 jumps on a SpartaTrac force plate, each separated by 15s rest. Sparta software computed 3 outputs: Load, Explode, and Drive. After baseline VJ calculation, all athletes performed an anaerobic fatigue protocol on a mechanically-braked cycle ergometer: 3 sprints lasting 15s separated by 10s rest. Peak and mean power were recorded from the cycle trials. Subjects then repeated the VJ protocol. This pattern was repeated until 6 sets of VJ were recorded. Repeated measures ANOVA tested differences between successive VJ performances. **Results.** Male athletes were 20.8 ± 1.5 years old, weighed 175.8 ± 14.0 lbs, had a baseline VJ of 46.9 ± 3.6 cm, Load of 53.6 ± 13.3, Explode of 49.4 ± 6.6, and Drive of 49.4 ± 11.9. Female athletes were 20.2 ± 1.2 years old, weighed 142.3 ± 13.2 lbs, had a baseline VJ of 32.7 ± 4.3 cm, Load of 49.8 ± 46.1, Explode of 40.7 ± 8.0, and Drive of 63.1 ± 49.7. The only differences between men and women were weight ($p<0.001$), VJ ($p<0.001$), and Explode ($p=0.006$). ANOVA found VJ height to decrease between baseline and trial 2 ($p<0.001$); there was no difference between men and

women (p=0.210); between trials 2 and 6, VJ height was consistent (p>0.400). Load was not affected by the fatigue protocol across the total sample (p=0.418) or by sex (p=0.239). Explode was not affected by fatigue across the sample (p=0.233) or by sex (p=0.406). Drive was affected by fatigue (p=0.040), decreasing in successive trials; there was no interaction with sex (p=0.742). **Conclusion**. VJ is more sensitive to fatigue than SpartaTrac force plate calculations. An initial fatiguing insult was sufficient to compromise performance, whereas accumulated fatigue did not have an additive effect. Drive was the only variable in SpartaTrac outputs that was affected by fatigue.

Introduction

During the last 20 years, technological advances, in part by Sparta Sport Performance, have publicized how ground reaction forces determined by the vertical jump can be used as a tool to monitor athlete wellness. One main goal for head coaches, strength coaches, and athletic trainers is to safely design a plan for their athletes to stay competitive at the highest level. If accessible technology can enhance an athlete's on-field performance using the athlete's reliable, quick, and understandable data, athletic departments should implement this technology.

The athletics department at the University of the Pacific frequently utilizes vertical jump tests as a quantitative tool in tracking athlete wellness. In 2018, all athletes were tested with the Kistler force plate and SpartaTrac software to create healthier, stronger, and more connected athletes. Strength trainers are able to alter training sessions and provide feedback to the coaching and athletic training staff based on the individualized Movement Signatures stemming from the technology. The Vertical Jump Test measures the ability to display power, explosive strength, and the ability to use that strength in a specific direction. With explosive movements, comes overtraining due to fatigue. It's inevitable to feel fatigue during intense training and understanding its effect on the human body is important, especially for high-level competition.

To our knowledge, evidence on jumping kinetics with acute fatigue performed on a friction-loaded cycle ergometer is limited in DI collegiate athletes, with even less research using SpartaTrac software. (Rodacki et al., 2002) This study will be able to fill this gap in by examining velocity and power losses during repeated sprints on an assault bike.

The objectives of the present investigation are: 1) Determine if a repeated 15s cycle sprint to 10s rest interval adequate applies anaerobic threshold in DI athletes, 2) Analyze how Movement Signatures respond to anaerobic activity, 3) Investigate how levels of power output affects the athlete's jump height, and 4) Determine the correlation between vertical jump performance and recovery to peak performance. The potential validation of a simple procedure of the vertical jump as a predictor of athlete fatigue and recovery time is the primary benefit.

Methods

A cross-sectional experimental design investigated the influence of fatigue on CMJ force-time characteristics in a randomized group of elite college athletes. Thirty-five male (n = 9, age: 20.8 ± 1.5 y; body mass: 1.84 ± 0.08 kg) and female (n = 26, age: 20.2 ± 1.2 y; body mass: 1.71 ± 0.05 kg) skilled athletes (soccer, baseball, swimming, and track & field) reported to the Pacific Athletics Training Facility for a single 30-min testing procedure. Data was collected in November and April during the off-season to avoid limitations in competition schedules. Subjects were informed with all test procedures 2 weeks before the experiment date. Each subject was asked to properly prepare for the assessment (i.e., no strenuous training at least 24 hours prior to the test, wearing athletic attire, and adequate amounts of food, water, and sleep), and was scheduled individually to ensure the integrity of data collection. Anthropometric measurements (height, BMI) and other variables were first gathered. A standardized 4-min dynamic warm-up of lower-body stretches, mobility exercises, and submaximal VJs prepared the subjects for maximal-effort assessment. A 2-min rest period was given after the warm up and a CMJ baseline trial was performed before commencement of jump testing. The testing protocol involved an assault bike, a force plate and a laptop with data analysis software. No technique was instructed during the experiment. All subjects were well conditioned and familiar with the exercises as they were both performed regularly during their sports training programs.

Results

Soccer males were taller, heavier and had a larger body mass. Insufficient data was used to determine sex differences of other sports. The data collected and shown in APPENDIX B were statistically significant in all paired samples ($p<0.05$). Figure 4 shows a multiple linear regressions model between sex and sport position, which is significant among females ($r=0.553$, $p<0.001$). Twenty-five percent of the population was male, which could explain their insignificant correlation. An insignificant and weak correlation ($r=0.325$, $p=0.09$) between maximum power and wattage reduction, explains that overall powerful athletes don't fatigue more quickly. Another weak correlation between peak power and watt reduction ($r=0.297$, $p=0.14$) was found because cycle power and jump height did not always drop. The estimated marginal means for load, explode, and drive show that after the first fatigue test, the athlete significantly drops in peak power, and stays consistent with no change in fatigue ($p<0.0001$).

Discussion

Pearson correlation and bivariate analysis of variation between the different variable depicted in APPENDIX B shows that as power position becomes higher, the jump height loss gets greater. High power production and having more body mass makes vertical jumping more tiresome, thus the sprinter loses vertical inches more than the endurance athlete. This suggests that jumping fatigue and power fatigue are different types of fatigue, and that positional power is hard to label because the same person may measure differently than others or have dissimilar muscle types than others in the same position. A learning curve was present either with how to jump higher or pedal faster after a couple of tries. The body also gets warmed up, and studies with postactivation potentiation show that a heavy load warm up can acutely enhance explosive strength performance in athletes. (Chiu et al., 2003) The null hypothesis was rejected when the correlation between cycle power and jump height was insignificant and changeable after the first fatigue test. It would be suggested to do more rounds to start to see fatigue. The regression shows a predication that position should have a significant effect on the athlete's fatigue. The null hypothesis was rejected when the correlation between peak power and change in wattage was insignificant, therefore my study shows that power athletes don't fatigue more quickly than it is perceived.

Practical Applications

Power produced either with the vertical jump or the assault bike is not a very important parameter to explain fatigue in Division I collegiate student athletes. This information could be useful for strength and conditioning coaches or athletics trainers to monitor their strength training programs to improve power output and thus strength and speed. Future research with plyometrics or light load resistance is required to refine the efficiency of anaerobic performance for more power and velocity used effectively during athletic competition, rather than traditional high magnitudes of heavy lifting. Athletes with low Load and high Drive should refrain from over stretching, and focus more on strength training to avoid injury, whereas high Explode and low Drive should stretch more to avoid injury.

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APPENDIX A: PAIRED SAMPLES T-TEST

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Load_1	44.46	35	9.394	1.588
	Load_2	44.66	35	11.248	1.901
Pair 2	Load_1	44.46	35	9.394	1.588
	Load_3	44.17	35	9.978	1.687
Pair 3	Load_1	44.46	35	9.394	1.588
	Load_4	43.34	35	10.335	1.747
Pair 4	Load_1	44.46	35	9.394	1.588
	Load_5	43.80	35	10.510	1.777
Pair 5	Load_1	44.29	31	9.213	1.655
	Load_6	43.84	31	9.798	1.760
Pair 6	Load_2	44.66	35	11.248	1.901
	Load_3	44.17	35	9.978	1.687
Pair 7	Load_2	44.66	35	11.248	1.901
	Load_4	43.34	35	10.335	1.747
Pair 8	Load_2	44.66	35	11.248	1.901
	Load_5	43.80	35	10.510	1.777
Pair 9	Load_2	43.77	31	10.468	1.880
	Load_6	43.84	31	9.798	1.760
Pair 10	Load_3	44.17	35	9.978	1.687
	Load_4	43.34	35	10.335	1.747
Pair 11	Load_3	44.17	35	9.978	1.687
	Load_5	43.80	35	10.510	1.777
Pair 12	Load_3	43.65	31	9.687	1.740
	Load_6	43.84	31	9.798	1.760
Pair 13	Load_4	43.34	35	10.335	1.747
	Load_5	43.80	35	10.510	1.777
Pair 14	Load_4	42.87	31	10.233	1.838
	Load_6	43.84	31	9.798	1.760
Pair 15	Load_5	43.48	31	10.491	1.884
	Load_6	43.84	31	9.798	1.760

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Explode_1	44.63	35	8.164	1.380
	Explode_2	43.34	35	9.168	1.550
Pair 2	Explode_1	44.63	35	8.164	1.380
	Explode_3	42.43	35	8.763	1.481
Pair 3	Explode_1	44.63	35	8.164	1.380
	Explode_4	42.51	35	9.211	1.557
Pair 4	Explode_1	44.63	35	8.164	1.380
	Explode_5	42.91	35	9.382	1.586
Pair 5	Explode_1	44.68	31	8.084	1.452
	Explode_6	43.10	31	10.300	1.850
Pair 6	Explode_2	43.34	35	9.168	1.550
	Explode_3	42.43	35	8.763	1.481
Pair 7	Explode_2	43.34	35	9.168	1.550
	Explode_4	42.51	35	9.211	1.557
Pair 8	Explode_2	43.34	35	9.168	1.550
	Explode_5	42.91	35	9.382	1.586
Pair 9	Explode_2	43.13	31	9.229	1.658
	Explode_6	43.10	31	10.300	1.850
Pair 10	Explode_3	42.43	35	8.763	1.481
	Explode_4	42.51	35	9.211	1.557
Pair 11	Explode_3	42.43	35	8.763	1.481
	Explode_5	42.91	35	9.382	1.586
Pair 12	Explode_3	42.32	31	9.134	1.640
	Explode_6	43.10	31	10.300	1.850
Pair 13	Explode_4	42.51	35	9.211	1.557
	Explode_5	42.91	35	9.382	1.586
Pair 14	Explode_4	42.55	31	9.605	1.725
	Explode_6	43.10	31	10.300	1.850
Pair 15	Explode_5	43.00	31	9.856	1.770
	Explode_6	43.10	31	10.300	1.850

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Drive_1	54.11	35	9.809	1.658
	Drive_2	53.03	35	10.092	1.706
Pair 2	Drive_1	54.11	35	9.809	1.658
	Drive_3	52.86	35	10.746	1.816
Pair 3	Drive_1	54.11	35	9.809	1.658
	Drive_4	51.86	35	11.589	1.959
Pair 4	Drive_1	54.11	35	9.809	1.658
	Drive_5	51.91	35	12.205	2.063
Pair 5	Drive_1	53.74	31	9.771	1.755
	Drive_6	49.42	31	10.844	1.948
Pair 6	Drive_2	53.03	35	10.092	1.706
	Drive_3	52.86	35	10.746	1.816
Pair 7	Drive_2	53.03	35	10.092	1.706
	Drive_4	51.86	35	11.589	1.959
Pair 8	Drive_2	53.03	35	10.092	1.706
	Drive_5	51.91	35	12.205	2.063
Pair 9	Drive_2	52.42	31	9.868	1.772
	Drive_6	49.42	31	10.844	1.948
Pair 10	Drive_3	52.86	35	10.746	1.816
	Drive_4	51.86	35	11.589	1.959
Pair 11	Drive_3	52.86	35	10.746	1.816
	Drive_5	51.91	35	12.205	2.063
Pair 12	Drive_3	52.35	31	10.544	1.894
	Drive_6	49.42	31	10.844	1.948
Pair 13	Drive_4	51.86	35	11.589	1.959
	Drive_5	51.91	35	12.205	2.063
Pair 14	Drive_4	51.16	31	11.463	2.059
	Drive_6	49.42	31	10.844	1.948
Pair 15	Drive_5	51.55	31	12.209	2.193
	Drive_6	49.42	31	10.844	1.948

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Load_1 & Load_2	35	.918	.000
Pair 2	Load_1 & Load_3	35	.948	.000
Pair 3	Load_1 & Load_4	35	.907	.000
Pair 4	Load_1 & Load_5	35	.896	.000
Pair 5	Load_1 & Load_6	31	.881	.000
Pair 6	Load_2 & Load_3	35	.948	.000
Pair 7	Load_2 & Load_4	35	.923	.000
Pair 8	Load_2 & Load_5	35	.915	.000
Pair 9	Load_2 & Load_6	31	.866	.000
Pair 10	Load_3 & Load_4	35	.963	.000
Pair 11	Load_3 & Load_5	35	.949	.000
Pair 12	Load_3 & Load_6	31	.941	.000
Pair 13	Load_4 & Load_5	35	.975	.000
Pair 14	Load_4 & Load_6	31	.975	.000
Pair 15	Load_5 & Load_6	31	.956	.000

		N	Correlation	Sig.
Pair 1	Explode_1 & Explode_2	35	.922	.000
Pair 2	Explode_1 & Explode_3	35	.887	.000
Pair 3	Explode_1 & Explode_4	35	.861	.000
Pair 4	Explode_1 & Explode_5	35	.802	.000
Pair 5	Explode_1 & Explode_6	31	.846	.000
Pair 6	Explode_2 & Explode_3	35	.930	.000
Pair 7	Explode_2 & Explode_4	35	.914	.000
Pair 8	Explode_2 & Explode_5	35	.875	.000
Pair 9	Explode_2 & Explode_6	31	.878	.000
Pair 10	Explode_3 & Explode_4	35	.972	.000
Pair 11	Explode_3 & Explode_5	35	.933	.000
Pair 12	Explode_3 & Explode_6	31	.944	.000
Pair 13	Explode_4 & Explode_5	35	.961	.000
Pair 14	Explode_4 & Explode_6	31	.943	.000
Pair 15	Explode_5 & Explode_6	31	.952	.000

		N	Correlation	Sig.
Pair 1	Drive_1 & Drive_2	35	.922	.000
Pair 2	Drive_1 & Drive_3	35	.886	.000
Pair 3	Drive_1 & Drive_4	35	.857	.000
Pair 4	Drive_1 & Drive_5	35	.863	.000
Pair 5	Drive_1 & Drive_6	31	.861	.000
Pair 6	Drive_2 & Drive_3	35	.916	.000
Pair 7	Drive_2 & Drive_4	35	.899	.000
Pair 8	Drive_2 & Drive_5	35	.868	.000
Pair 9	Drive_2 & Drive_6	31	.900	.000
Pair 10	Drive_3 & Drive_4	35	.942	.000
Pair 11	Drive_3 & Drive_5	35	.933	.000
Pair 12	Drive_3 & Drive_6	31	.892	.000
Pair 13	Drive_4 & Drive_5	35	.914	.000
Pair 14	Drive_4 & Drive_6	31	.921	.000
Pair 15	Drive_5 & Drive_6	31	.904	.000

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Load_1 - Load_2	-.200	4.568	.772	-1.769	1.369	-.259	34	.797
Pair 2	Load_1 - Load_3	.286	3.168	.535	-.802	1.374	.534	34	.597
Pair 3	Load_1 - Load_4	1.114	4.344	.734	-.378	2.606	1.518	34	.138
Pair 4	Load_1 - Load_5	.657	4.677	.791	-.950	2.264	.831	34	.412
Pair 5	Load_1 - Load_6	.452	4.668	.838	-1.261	2.164	.539	30	.594
Pair 6	Load_2 - Load_3	.486	3.633	.614	-.762	1.734	.791	34	.434
Pair 7	Load_2 - Load_4	1.314	4.323	.731	-.171	2.799	1.798	34	.081
Pair 8	Load_2 - Load_5	.857	4.532	.766	-.700	2.414	1.119	34	.271
Pair 9	Load_2 - Load_6	-.065	5.285	.949	-2.003	1.874	-.068	30	.946
Pair 10	Load_3 - Load_4	.829	2.792	.472	-.130	1.788	1.756	34	.088
Pair 11	Load_3 - Load_5	.371	3.326	.562	-.771	1.514	.661	34	.513
Pair 12	Load_3 - Load_6	-.194	3.361	.604	-1.426	1.039	-.321	30	.751
Pair 13	Load_4 - Load_5	-.457	2.331	.394	-1.258	.343	-1.160	34	.254
Pair 14	Load_4 - Load_6	-.968	2.273	.408	-1.801	-.134	-2.371	30	.024
Pair 15	Load_5 - Load_6	-.355	3.083	.554	-1.486	.776	-.641	30	.526

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Explode_1 - Explode_2	1.286	3.561	.602	.062	2.509	2.136	34	.040
Pair 2	Explode_1 - Explode_3	2.200	4.064	.687	.804	3.596	3.202	34	.003
Pair 3	Explode_1 - Explode_4	2.114	4.695	.794	.501	3.727	2.664	34	.012
Pair 4	Explode_1 - Explode_5	1.714	5.639	.953	-.223	3.651	1.799	34	.081
Pair 5	Explode_1 - Explode_6	1.581	5.524	.992	-.446	3.607	1.593	30	.122
Pair 6	Explode_2 - Explode_3	.914	3.381	.572	-.247	2.076	1.600	34	.119
Pair 7	Explode_2 - Explode_4	.829	3.808	.644	-.479	2.137	1.287	34	.207
Pair 8	Explode_2 - Explode_5	.429	4.635	.784	-1.164	2.021	.547	34	.588
Pair 9	Explode_2 - Explode_6	.032	4.929	.885	-1.776	1.840	.036	30	.971
Pair 10	Explode_3 - Explode_4	-.086	2.188	.370	-.837	.666	-.232	34	.818
Pair 11	Explode_3 - Explode_5	-.486	3.373	.570	-1.644	.673	-.852	34	.400
Pair 12	Explode_3 - Explode_6	-.774	3.461	.622	-2.044	.495	-1.245	30	.223
Pair 13	Explode_4 - Explode_5	-.400	2.592	.438	-1.290	.490	-.913	34	.368
Pair 14	Explode_4 - Explode_6	-.548	3.443	.618	-1.811	.715	-.887	30	.382
Pair 15	Explode_5 - Explode_6	-.097	3.145	.565	-1.250	1.057	-.171	30	.865

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Drive_1 - Drive_2	1.086	3.929	.664	-.264	2.435	1.635	34	.111
Pair 2	Drive_1 - Drive_3	1.257	4.984	.843	-.455	2.969	1.492	34	.145
Pair 3	Drive_1 - Drive_4	2.257	5.977	1.010	.204	4.310	2.234	34	.032
Pair 4	Drive_1 - Drive_5	2.200	6.211	1.050	.066	4.334	2.096	34	.044
Pair 5	Drive_1 - Drive_6	4.323	5.534	.994	2.293	6.352	4.349	30	.000
Pair 6	Drive_2 - Drive_3	.171	4.322	.730	-1.313	1.656	.235	34	.816
Pair 7	Drive_2 - Drive_4	1.171	5.079	.858	-.573	2.916	1.365	34	.181
Pair 8	Drive_2 - Drive_5	1.114	6.091	1.030	-.978	3.207	1.082	34	.287
Pair 9	Drive_2 - Drive_6	3.000	4.726	.849	1.267	4.733	3.534	30	.001
Pair 10	Drive_3 - Drive_4	1.000	3.888	.657	-.336	2.336	1.522	34	.137
Pair 11	Drive_3 - Drive_5	.943	4.432	.749	-.580	2.465	1.259	34	.217
Pair 12	Drive_3 - Drive_6	2.935	4.986	.896	1.107	4.764	3.278	30	.003
Pair 13	Drive_4 - Drive_5	-.057	4.976	.841	-1.766	1.652	-.068	34	.946
Pair 14	Drive_4 - Drive_6	1.742	4.472	.803	.102	3.382	2.169	30	.038
Pair 15	Drive_5 - Drive_6	2.129	5.214	.936	.217	4.041	2.274	30	.030

APPENDIX B: BIVARIATE CORRELATIONS TABLE

		JH Loss from 1 to 2	Sex	Sleep (hrs) night before	Diet Quality (scale 1-10)	Injury Status	Position (coded) 1=low power	Height	Weight	BMI	JH 1 (cm)	JH Avg (cm)	Load_1	Load_Avg	Explode_1	Explode Avg	Drive_1	Drive Avg	Watts_1_1	Watts_1_2	Watts_1_3
JH Loss from 1 to 2	*r*	1	.326	.009	-.046	-.218	-.552**	-.273	-.468**	-.418*	-.435**	-.384*	-.198	.011	-.018	.100	-.167	.058	-.365*	-.299	-.184
	p	NA	.056	.959	.791	.209	.001	.112	.005	.012	.009	.023	.253	.949	.919	.569	.339	.740	.031	.081	.289
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Sex	*r*	.326	1	-.153	-.195	.227	-.105	-.706**	-.749**	-.315	-.839**	-.826**	-.515**	-.042	-.458**	-.454**	.277	.139	-.558**	-.589**	-.481**
	p	.056	NA	.379	.262	.189	.548	.000	.000	.065	.000	.000	.002	.811	.006	.006	.107	.426	.000	.000	.003
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Sleep (hrs) night before	*r*	.009	-.153	1	.255	-.036	.081	.048	.043	.006	.018	.043	.257	.003	.125	.083	-.196	-.084	.037	.048	.045
	p	.959	.379	NA	.140	.837	.644	.786	.805	.973	.917	.805	.136	.985	.473	.636	.260	.633	.831	.783	.798
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Diet Quality (scale 1-10)	*r*	-.046	-.195	.255	1	-.078	.093	.069	.214	.261	.129	.127	.041	-.193	.084	-.031	-.104	.059	.171	.192	.132
	p	.791	.262	.140	NA	.656	.596	.695	.218	.130	.462	.468	.816	.267	.631	.859	.551	.737	.326	.269	.450
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Injury Status	*r*	-.218	.227	-.036	-.078	1	.299	-.264	-.107	.151	-.197	-.234	-.147	.236	-.089	-.082	-.099	-.120	-.365*	-.326	-.257
	p	.209	.189	.837	.656	NA	.081	.125	.541	.388	.256	.177	.398	.173	.612	.639	.571	.494	.031	.056	.136
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Position (coded) 1=low power	*r*	-.552**	-.105	.081	.093	.299	1	.380*	.354*	.091	.260	.261	.176	-.031	-.072	-.105	.218	-.080	.223	.215	.243
	p	.001	.548	.644	.596	.081	NA	.024	.037	.603	.132	.130	.313	.858	.680	.546	.208	.648	.198	.216	.159
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Height	*r*	-.273	-.706**	.048	.069	-.264	.380*	1	.789**	.036	.657**	.670**	.373*	-.015	.214	.277	.072	-.185	.771**	.794**	.723**
	p	.112	.000	.786	.695	.125	.024	NA	.000	.836	.000	.000	.027	.933	.217	.107	.682	.286	.000	.000	.000
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Weight	*r*	-.468**	-.749**	.043	.214	-.107	.354*	.789**	1	.641**	.681**	.658**	.467**	.026	.202	.204	.050	-.023	.762**	.737**	.619**
	p	.005	.000	.805	.218	.541	.037	.000	NA	.000	.000	.000	.005	.884	.245	.240	.775	.895	.000	.000	.000
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
BMI	*r*	-.418*	-.315	.006	.261	.151	.091	.036	.641**	1	.265	.209	.254	.051	.033	-.040	.020	.206	.297	.222	.108
	p	.012	.065	.973	.130	.388	.603	.836	.000	NA	.124	.229	.141	.773	.849	.818	.910	.236	.083	.199	.539
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
JH 1 (cm)	*r*	-.435**	-.839**	.018	.129	-.197	.260	.657**	.681**	.265	1	.990**	.620**	.102	.565**	.547**	-.109	-.231	.568**	.574**	.555**
	p	.009	.000	.917	.462	.256	.132	.000	.000	.124	NA	.000	.000	.561	.000	.001	.532	.183	.000	.000	.001
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
JH Avg (cm)	*r*	-.384*	-.826**	.043	.127	-.234	.261	.670**	.658**	.209	.990**	1	.618**	.101	.560**	.561**	-.107	-.233	.570**	.580**	.583**
	p	.023	.000	.805	.468	.177	.130	.000	.000	.229	.000	NA	.000	.564	.000	.000	.542	.178	.000	.000	.000
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Load_1	*r*	-.198	-.515**	.257	.041	-.147	.176	.373*	.467**	.254	.620**	.618**	1	.211	.556**	.568**	-.307	-.249	.318	.337*	.388*
	p	.253	.002	.136	.816	.398	.313	.027	.005	.141	.000	.000	NA	.223	.001	.000	.073	.150	.063	.048	.021
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Load_Avg	*r*	.011	-.042	.003	-.193	.236	-.031	-.015	.026	.051	.102	.101	.211	1	.190	.335*	-.144	-.112	-.093	-.128	.013
	p	.949	.811	.985	.267	.173	.858	.933	.884	.773	.561	.564	.223	NA	.274	.049	.410	.522	.595	.462	.940
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Explode_1	*r*	-.018	-.458**	.125	.084	-.089	-.072	.214	.202	.033	.565**	.560**	.556**	.190	1	.904**	-.774**	-.394*	.145	.210	.245
	p	.919	.006	.473	.631	.612	.680	.217	.245	.849	.000	.000	.001	.274	NA	.000	.000	.019	.405	.226	.156
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Explode Avg	*r*	.100	-.454**	.083	-.031	-.082	-.105	.277	.204	-.040	.547**	.561**	.568**	.335*	.904**	1	-.679**	-.289	.128	.233	.293
	p	.569	.006	.636	.859	.639	.546	.107	.240	.818	.001	.000	.000	.049	.000	NA	.000	.093	.463	.178	.087
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Drive_1	*r*	-.167	.277	-.196	-.104	-.099	.218	.072	.050	.020	-.109	-.107	-.307	-.144	-.774**	-.679**	1	.276	.158	.045	.021
	p	.339	.107	.260	.551	.571	.208	.682	.775	.910	.532	.542	.073	.410	.000	.000	NA	.108	.364	.799	.903
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Drive Avg	*r*	.058	.139	-.084	.059	-.120	-.080	-.185	-.023	.206	-.231	-.233	-.249	-.112	-.394*	-.289	.276	1	-.050	-.029	-.092
	p	.740	.426	.633	.737	.494	.648	.286	.895	.236	.183	.178	.150	.522	.019	.093	.108	NA	.774	.867	.599
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Watts_1_1	*r*	-.365*	-.558**	.037	.171	-.365*	.223	.771**	.762**	.297	.568**	.570**	.318	-.093	.145	.128	.158	-.050	1	.896**	.736**
	p	.031	.000	.831	.326	.031	.198	.000	.000	.083	.000	.000	.063	.595	.405	.463	.364	.774	NA	.000	.000
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Watts_1_2	*r*	-.299	-.589**	.048	.192	-.326	.215	.794**	.737**	.222	.574**	.580**	.337*	-.128	.210	.233	.045	-.029	.896**	1	.868**
	p	.081	.000	.783	.269	.056	.216	.000	.000	.199	.000	.000	.048	.462	.226	.178	.799	.867	.000	NA	.000
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
Watts_1_3	*r*	-.184	-.481**	.045	.132	-.257	.243	.723**	.619**	.108	.555**	.583**	.388*	.013	.245	.293	.021	-.092	.736**	.868**	1
	p	.289	.003	.798	.450	.136	.159	.000	.000	.539	.001	.000	.021	.940	.156	.087	.903	.599	.000	.000	NA
	n	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

r= Pearson correlation; *p*=significance 2-tailed