The Effects of Plyometric Training Volume and Surface Composition on Jump Performance

By

Cameron Addie

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Human Performance

Middle Tennessee State University
April, 2024

Dissertation Committee:

Dr. Samantha L. Johnson, Chair

Dr. Jennifer L. Caputo

Dr. Dana K. Fuller

ACKNOWLEDGMENTS

I am immensely grateful for the support and guidance of my dissertation committee, comprised of Dr. Samantha Johnson, Dr. Jenn Caputo, and Dr. Dana Fuller. Their dedication and investment of time were integral to the success of this dissertation. I want to express my deepest appreciation to each of them for their invaluable contributions. Dr. Johnson and Dr. Caputo, I cannot thank you enough for your mentorship and unwavering support throughout this challenging process. Your guidance has been invaluable, and I am truly fortunate to have had such outstanding mentors. Your assistance in improving my writing skills has been immensely helpful, and I am grateful for the progress I have made under your guidance. Dr. Fuller, I am sincerely grateful for your expertise in statistics and results analysis. Your dedication to assisting me has been instrumental, and I am thankful for your support. I am blessed to have had such a remarkable committee at Middle Tennessee State University (MTSU). Your guidance allowed me to stay true to myself while navigating this journey. I am deeply appreciative of your collective wisdom and encouragement. I also extend my gratitude to the professors, classmates, friends, and family who supported me throughout my time at MTSU. Your encouragement and patience were invaluable. Lastly, I want to acknowledge myself. Despite facing numerous challenges, I persevered through this process. With the support of my committee, loved ones, and peers, I stayed true to myself, and I am proud of the outcome.

ABSTRACT

Plyometric training (PT) is a popular method used to improve vertical and horizontal jump performance. However, the influence of training surface and volume on the effectiveness of PT remains unclear. The purpose of this dissertation was to examine the effects of training surface and volume following a 6-week PT program on jump performance in physically active individuals (PAI). For study 1, participants (N = 18) completed a 6-week PT program on either a soft (2-inch foam surface; n = 9) or hard (hardwood gymnasium floor; n = 9) surface. Vertical jump performance was assessed by squat jump (SJ), counter-movement jump (CMJ), and approach jump (AJ) before and after the PT program. For Study 2, participants (N = 12) completed a 6-week PT program with either moderate volume (1460 total foot contacts) or high volume (1850 total foot contacts).Jump performance was assessed using broad jump (BJ), SJ, CMJ, AJ. Participants for both studies were recruited through email at Middle Tennessee State University. The results of the first study indicated significant improvement in SJ, CMJ, and AJ regardless of training surface. The results of the second study similarly indicated significant improvement from pre- to post-testing for BJ, CMJ, and AJ, regardless of training volume. Notably, neither training group exhibited significant improvements in SJ performance. Considering the findings of these studies, practitioners looking to elicit improvements in vertical jump should align the PT training surface with individual needs, preferences, and resources. Additionally, improvements in vertical and horizontal jump performance can be elicited with programs as low as 1460 total foot contacts. With the two volumes utilized in this dissertation, there is no apparent benefit to the higher training volume based on the outcomes measured.

TABLE OF CONTENTS

Page

LIST OF TABLES viii

LIST OF APPENDICES ix

CHAPTER I: DISSERTATION INTRODUCTION 1

Purpose of the Study 4

Significance of the Study 4

CHAPTER II: REVIEW OF LITERATURE 6

Introduction 6

Theoretical Basis of Plyometric Adaptions 6

Mechanical Basis 6

Neural Basis 6

Motor Unit Recriutment 9

Synchronziation 9

Neural Drive to the Muscle 10

Synaptic Adaptions 11

Coniderations for Plyometric Training Program Design 13

Modaility 14

Upper Extremity 14

Trunk 15

Lower Extremity 15

Assisted and Resisted Plyometrics 15

Intensity 17
Volume 23
Recovery 25
Progression 26
Surface 27
Aquatic 27
Non-Rigid versus Rigid Surfaces 30
Summary 34
CHAPTER III: THE EFFECTS OF SURFACE COMPOSTION ON VERTICAL JUMP PERFORMANCE DURING A 6-WEEKS PLYOMETRIC TRAINING PROGRAM 36
Introduction 36
Methods 38
Study Design 38
Particpants 39
Materials and Procedures 40
Training Protocol 41
Statistical Analysis 42
Results 43
Squat Jump 43
Counter-Movment Jump 43
Approach Jump 43

Discussion 46

Conclusion 49

Chapter III References 50

APPENDIX FOR STUDY I………………………...…………………54

CHAPTER IV: THE EFFECTS OF PLYOMETRIC TRAINING VOLUME ON JUMP PERFORMANCE USING A6-WEEK PLYOMETRIC TRAINING PROGRAM………………………………………………………………………75

Introduction.. 75

Methods.. 77

Study Design 77

Particpants.. 78

Materials and Procedures 78

Training Protocol 80

Statistical Analysis... 86

Results.. 81

Broad Jump 81

Squat Jump.. 82

Counter-Movement Jump 82

Approach Jump 82

Discussion... 86

Chapter IV References.. 90

APPENDIX FOR STUDY II………………………...……………...93

CHAPTER V: CONCLUSION..………...…………………………………………..114

Overall Conclusion 117

Dissertation References 119

LIST OF TABLES

Page

Chapter 3

Table 1 6-Week Plyometric Training Program Protocol…………………………………………………………..44

Table 2 Descriptive Statistics for Surface Condition Jump Height (cm)..…………………………..45

Chapter 4

Table 1 6-Week Plyometric Training Program Protocol…………………………………………………………..83

Table 2 Descriptive Statistics for Performance Outcomes Based On Training Volume (cm)..…………………………..85

LIST OF APPENDICES

Page

Chapter 3

Appendix A IRB APPROVAL LETTER…….……………………………………..55

Appendix B CITI COURSEWORK REQUIREMENTS…..………………………….58

Appendix C INFORMED CONSENT…………………………………………...64

Appendix D PARTICIPANT SURVEY...………………...…………………………. 71

Appendix E EMAIL RECRUITMENT LETTER.……………………………………72

Chapter 4

Appendix A IRB APPROVAL LETTER…….……………………………………..94

Appendix B CITI COURSEWORK REQUIREMENTS…..………………………….97

Appendix C INFORMED CONSENT..………………………………………...103

Appendix D PARTICIPANT SURVEY..……………...……………………………110

Appendix E EMAIL RECRUITMENT LETTER…….……………………………….46

CHAPTER I

DISSERTATION INTRODUCTION

The ability to produce vertical and horizontal lower body power is important in sports such as basketball, football, volleyball, and track. One common method for increasing lower body power is through plyometric training (PT), which a category of strength training that involves jumping, sprinting, and throwing exercises. The exercises included in PT utilize the stretch-shorting cycle, where a muscle is stretched immediately before contraction (Young et al., 1995).

Neural adaptations are one source of improvement in lower body power following PT. These adaptations include increased motor unit recruitment, synchronization, and increased neural drive to the working muscles (Earle & Baechle, 2004; Gabriel et al., 2006). Adaptations to motor unit recruitment include recruiting more motor units, thus allowing an increase in force production (Aagaard, 2003 & Gabriel et al., 2006). Additionally, PT allows for improved synchronization of motor units also yielding an increase in force production (Earle & Baechle, 2004). Lastly, PT increases neural drive to the working muscles, increasing stimulation from the spinal motoneurons during maximal contraction causing an increase in motoneuronal output that increases power (Aagaard et al., 2002; Gabriel et al., 2006; Hakkukinen et al., 1985; Hedayatpour & Falla, 2015; Maffiuletti et al., 2002; Markovic & Mikulic, 2010; Moritani & deVries, 1979; & Robinson et al., 2004).

When programming for PT there are several factors to take into consideration, one of which is training surface. The majority of the time PT is performed on a hard surface such as a gymnasium floor. However, variations in training surface have been documented in the literature. Although the composition of hard and soft surfaces varies between studies, there are some key traits of hard and soft surfaces. Some significant characteristics for a hard surface would be minimal shock absorption, high rebound effect, and high impact on joints. Examples include wooden gymnasium floors and synthetic or concrete floors. Soft surfaces have higher shock absorption, reduced rebound, and lower impact on joints. Examples of soft surfaces include sand, water, and foam mats. Training surface may be= altered for several reasons, including performance optimization, injury prevention, PT variability, rehabilitation, and developmental or specialized training. For example, Ramírez-Campillo et al. (2013) identified that 7-weeks of PT on a soft surface (sand) yielded less muscle damage training than on a hard training surface (gymnasium floor). However, both groups increased vertical and horizontal jump performance. In consideration of these comparisons, it has been suggested that training on soft surfaces may result in enhancements to the musculoskeletal system, whereas training on hard surfaces may lead to neuromuscular enhancements (Ramirez-Campillo et al. 2013; Robinson et al., 2004).

Another component of PT to be taken into consideration is training volume (de Villarreal et al., 2009). Training volume is regularly quantified as the number of foot contacts per training session. Potach and Chu (2008) recommended 80 to 100, 100 to 120, and 120 to 140 foot contacts per training session for those with beginner, intermediate, and advanced experience, respectively. In accordance, Yanci et al. (2017) observed no difference in lower extremity power improvements in professional Futsal players following 6-week programs with one or two weekly training sessions, as long as weekly foot contacts remained similar (96-176/week). In support of the importance of weekly foot contacts being an appropriate measure of volume, Yanci et al. (2016) demonstrated no difference in horizontal power improvement following 6 weeks of training with 180 or 360 weekly foot contacts over two training sessions per week in professional male soccer players. Importantly, exceeding an individual's training volume limit in PT programs will not significantly improve jump performance compared to a lower volume, and may elevate the risk of overuse injuries (Çđmenlđ et al., 2016; Yanci et al. 2016). Hence, it is crucial to tailor the training volume and intensity according to everyone's training background and injury status. While there are studies examining the effect of training volume on adaptations with athletic populations, this remains to be explored with physically active individuals (PAI). Employing PAI as participants in this study is warranted, given its broad-ranging implications in areas such as health, performance, injury prevention, diversity in physical activity levels, motivation, and adherence to exercise programs, education, and the optimization of exercise programs for a diverse population. The findings of this research hold practical significance for individuals aiming to enhance their physical fitness and performance.

Currently most PT research on training volume and surface composition is performed with high school or elite athletic populations. There is a lack of research on PT for PAI. While their fitness goals may align, PAI often vary in training levels compared to elite athletes. Continuing research on this population allows fitness professionals to tailor PT programs to meet the specific needs and capabilities of this group.

Purpose of the Study

The purpose of the first study in this dissertation was to compare changes in vertical lower body power following 6-weeks of PT on a soft training surface (2-inch wrestling mat) versus a hard training surface (hardwood gymnasium floor) with PAI. Vertical lower body power was assessed with squat jumps (SJ), countermovement jumps (CMJ), and approach jumps (AJ). The second purpose of this study was to compare the effects of a 6-week PT program with 90-140 weekly foot contacts versus 115-180 weekly foot contact (30% increase) on vertical and horizontal lower body power in PAI. The outcomes were assessed on SJ, CMJ, AJ, and broad jump (BJ) performance.

Significance of the Study

This study will add to the body of knowledge of PT and will continue to shed insight on environmental factors (surface area) and program design (volume training). This material will aid in providing PT research on a diverse range of PAI which can lead to a broader understanding of PT impact on different demographic groups. This can help in addressing disparities in sports science research and ensuring that findings are applicable to a wider population. Investigating research on PAI will provide insight that can be directly applied to the everyday training and fitness routines to a large demographic.

CHAPTER II

REVIEW OF LITERATURE

Introduction

This review begins with background information on the theoretical basis of plyometric training. This includes the mechanical model and neural factors that affect plyometric training. Next are factors to consider when creating a plyometric training program, including modalities, intensity, volume, recovery, and progression. Lastly, the review covers the effects of performing plyometric training in water, as well as comparing the effects of training on rigid and non-rigid surfaces.

Theoretical Basis of Plyometric Adaptions

Mechanical Basis

The theory behind plyometric training is to increase power using movements that utilize the natural elastic components of muscles and tendons, as well as those that activate the stretch reflex (Smith & Clark, 2014). Plyometric exercise enables skeletal muscles to reach maximum strength as quickly as possible (Smith & Clark, 2014). Factors that affect the mechanical efficiency of power can be broken down into four categories including: (1) excitability of the brain to respond to a stimulus via neurotransmitters (acetylcholine); (2) contractility of the muscle to develop tension; (3) extensibility or the ability to lengthen or stretch (de Villarreal et al., 2009); and (4) elasticity of the muscle to return to resting length (Rassier et al., 1999; Smith & Clark, 2014).

This increase in power is achieved with the stretch-shortening cycle (SSC), which includes the eccentric pre-stretch, amortization, and concentric shortening phases. During the eccentric pre-stretch phase, the muscle-tendon unit and non-contractile tissues are stretched, which increases the force generated during the concentric phase. The non-contractile tissues consist of serial elastic components (SEC) and parallel elastic components (PEC). The SECs are in the tendons and aponeuroses and the PECs include the membranes surrounding the contractile components of the muscle (Rode et al., 2009). The amortization phase or transition phase occurs when the muscles change from lengthening to contracting (Ball & Scurr, 2009; Buğa & Gencer, 2022; Chu, 1998; Toumi et al., 2001). The shorter the amortization phase, the more efficient and explosive the movement concentric phase can be. An excessively long amortization phase can lead to decreased power output (Chu, 1998). Lasty the concentric phase occurs when the muscles generate force to propel the body upward or outward (Ball & Scurr, 2009; Buğa & Gencer, 2022; Chu, 1998; Toumi et al., 2001)

The use of plyometric exercise causes the SSC to activate the stretch reflex. The stretch reflex is activated by muscle spindles, which are sensory organs located in the muscle that measure the rate and magnitude of the muscle being stretched (Chu, 1998). The muscle spindles relay sensory input related to rapid muscle stretching for the activation of the stretch reflex (Radcliffe & Farentinos, 2015). Once the stretch reflex occurs the impulse signal travels along the spinal cord via the type 1a nerve fibers (Shah, 2012). After synapsing with the alpha motor neuron in the spinal cord, the impulse will travel to the agonist extrafusal fibers, causing a reflexive muscle action.

The faster the muscle is stretched during the eccentric phase, and if the amortization phase is concurrently short, the greater the concentric force generated during the concentric phase (Shah, 2012).

Neural Basis

The majority of adaptations that occur with plyometric result from neural adaptations. These adaptions are present within the central nervous system (CNS), peripheral nervous system (PNS), and the SSC (SEC, CC, PEC) components (Wang et al., 2020). The exact mechanisms of plyometric adaptions are unknown, but changes are seen in increased motor unit (MU) recruitment, rate coding, and firing rates (Markovic & Mikulic, 2010).

Neuromuscular adaptations are influenced by several characteristics of exercise, including mechanical tension, cellular damage, and metabolic stress applied to the muscle (Aagaard, 2003; Behrens et al., 2013; Hedayatpour & Falla, 2015). Neural adaptions play a significant role during the beginning phases of plyometric training, adaptions can occur within hours or days of initiating a plyometric training program and are thought to increase MU recruitment, synchronization of MU firing, and increased neural drive to the muscle (Earle & Baechle, 2004; Gabriel et al., 2006).

Overall, plyometric training induces several adaptations within the peripheral nervous system that contribute to improved athletic performance, especially in activities requiring explosive power and rapid changes in direction. These adaptations allow individuals to generate force quickly, maintain control during high-intensity movements, and potentially reduce the risk of injury.

Motor unit recruitment

Motor unit recruitment refers to the amount of nerve stimulation and the number of active MU during a muscular contraction (Earle & Baechle, 2004). A common method used to evaluate MU adaptations is surface electromyography (EMG; Mirzaei et al., 2013). During plyometric training the nervous system adapts by effectively synchronizing and recruiting more MU, causing an increase in maximal force output (Aagaard, 2003; Gabriel et al., 2006). There is evidence that performing plyometric training improves MU recruitment and maximum voluntary isometric contraction (MVIC; Earle & Baechle, 2004; Mirzaei et al., 2013; Rezaimanesh et al., 2011). Mirzaei et al. (2013) observed that two training sessions for 6-weeks of plyometric training increased MU recruitment for the experimental group during MVIC in the vastus medialis by 23% and rectus femoris by 35% compared to the control group. Similarly, in a study of 14 varsity futsal players, Rezaimanesh et al. (2011) observed that 4 weeks of plyometric training significantly increased EMG activity of the biceps femoris when performing a MVIC in the squat position and when performing the vertical jump.

Synchronization of motor unt firing

Motor unit synchronization involves the simultaneous activation and discharge of action potentials of numerous MU (Earle & Baechle, 2004). Synchronization of MU and their firing rates is a possible mechanism for increased muscular strength. Plyometric training has been noted to increase MU synchronization yielding an increase in force production (Gabriel et al., 2006). Masamoto et al. (2003) examined 12 males on acute effects of plyometric exercise one repetition maximum. Performing four weeks of tuck jumps and depth jump increased one repetition maximum by 3.5% indicating that individuals who perform plyometric exercises can improve intramuscular coordination (enhanced MU synchronization).

Neural drive to the muscle

Neural drive refers to the activation of motor neurons from the nervous system that are responsible for producing muscle contractions. Neural drive can be central or peripheral in origin and is assessed using EMG to detect changes in MU firing rate (Gabriel et al., 2006). The increased neural drive from plyometric training comes from the increased stimulation from V-wave response from the spinal motoneurons during maximal muscle contractions (Hakkukinen et al., 1985). The H-reflex is also observed to enhance drive in the descending corticospinal pathway, causing an elevated motoneuron excitability and alteration in presynaptic inhibition 1a afferent motor neurons in the agonist muscle (Hakkukinen et al., 1985). The increase in motoneuronal output has been shown to increase power and strength after plyometric training (Aagaard et al., 2002; Gabriel et al., 2006; Hakkukinen et al., 1985; Hedayatpour & Falla, 2015; Maffiuletti et al., 2002; Markovic & Mikulic, 2010; Moritani & deVries, 1979). There is also evidence neural drive to the muscle is enhanced from plyometrics, yielding an increase in lower extremity power. These adaptations can be seen in as little as 2-4 weeks of plyometric training when performing a minimum of 50 jumps per training session (Aagaard et al., 2002; Gabriel et al., 2006; Hakkukinen et al., 1985; Hedayatpour & Falla, 2015; Maffiuletti et al., 2002; Markovic & Mikulic, 2010).

Synaptic adaptations

A synapse is a specialized junction between neurons and their target cells, allowing for transmission of signals from one cell to another (Keshishian et al., 1996). Plyometric training has been shown to alter the efficacy between 1a afferent alpha motoneurons leading to increased action potentials to the spine. The increased signal gives an excitatory postsynaptic potential leading to the enhancement of MU activation towards the muscle (Aagaard et al., 2002; Gabriel et al., 2006; Hedayatpour & Falla, 2015). While plyometric training has been shown to acutely increase synaptic strength and efficacy in as little as 2 weeks of training, long term plyometric training has been shown to yield the same synaptic strength and efficacy benefits, which additional morphological changes through the formation of new synapses (Hedayatpour & Falla, 2015).

Motoneurons have the potential to increase muscle activation. In contrast, Golgi tendon organs (GTOs) are sensory receptors located in the tendons that connect muscle to bone. The GTOs signal the spinal cord via Ib afferent nerve fibers when activated by stretch, generating tension within the muscle-tendon unit (Baker, 2003; Turner & Jeffreys, 2010). The activation of these Ib fibers results in autogenic inhibition of the agonist muscle and facilitation of the antagonist muscle, which serves as a protective mechanism to prevent the generation of harmful muscular forces (Komi, 2000). It is important to note that the relationship between agonist and antagonist muscle activity is complex and multifaceted and may not always follow the traditional model of opposing muscle groups. Some research suggests that increased antagonist muscle activity during certain movements may be beneficial for joint stability and injury prevention (Baker, 2003; Komi, 2000; Turner & Jeffreys, 2010). Plyometric training is often thought to be a training modality to desensitize the GTO to allow for greater muscle contraction (Chu, 1998).

Changes in input and output of the GTOs may occur because of plyometric training. It has been suggested that plyometric training may down-regulate Ib afferent feedback (autogenous inhibitory feedback) to the spinal motoneuron pool, perhaps due to modulation via supraspinal pathways (Turner & Jeffreys, 2010). With a college-aged sample that was unfamiliar with high intensity plyometric exercise (such as 24- and 36-inch depth jumps), Schmidtbleicher et al. (1998) reported up to a 50% decrease in EMG activation in the soleus muscle lasting up to 200 milliseconds during ground contact. However, trained individuals accustomed to depth jumps at those heights showed reduced inhibitory effects and were able to undergo high eccentric landing forces without a decrease in muscular force (Schmidtbleicher et al., 1998).

Renshaw cells are a type of inhibitory interneuron located in the spinal cord and that play a crucial role in neurotransmitter inhibition, preventing hyperexcitability of motor neuron activity (Baker, 2003). Renshaw cells help to regulate the strength and duration of muscle contractions, preventing them from becoming too strong or long-lasting (Baker, 2003). The effect of plyometric training on Renshaw cells has not been extensively studied and the research that exists is limited. The theory that plyometric training may cause changes in receptor morphology and activation of spinal reflex pathways that involve Renshaw cell inhibition following plyometric suggests that the effects are more subtle or inconsistent depending on the individual and specific training intensities used (Baker, 2003; Komi, 2000).

In summary, plyometric training engages both the central nervous system and the peripheral nervous system in a coordinated manner to improve motor control, coordination, and the ability to generate explosive force. These neural adaptations are essential for athletes and individuals seeking to enhance their athletic performance while maintaining stability and minimizing the risk of injury. Designing an effective plyometric training program requires careful consideration of various factors to ensure safety, effectiveness, and the achievement of specific training goals.

Considerations for Plyometric Training Program Design

Plyometric training involves various jumping, springing, and throwing movements. When designing an effective plyometric training program, Haff & Triplett (2021) suggest that it is important to consider characteristics such as sex, age, training level, sport, familiarity with plyometrics, relative strength (back squat of 1.5 times body weight), and landing mechanics. Designing a plyometric training program tailored to an individual allows them to increase their strength and optimize plyometric training performance outcomes (Radin, 2009). Overall practitioners should use their best judgment based on the individual's characteristics (sex, age, training level, sport, familiarity with plyometric, relative strength [back squat of 1.5 times body weight], and landing mechanics) when determining an athlete's readiness to perform plyometric exercise. Ideally plyometric training will be implemented when training volume overall is low and the training emphasis is on strength and power (Herrington et al., 2015).

However, plyometric training may still be implemented during times of high volume as a useful warm-up to prepare the body for conditioning and to improve landing mechanics as a measure to reduce injury risk (Herrington et al., 2015). Plyometric modality refers to the specific types or categories of plyometric exercises used in a plyometric training program. Plyometric exercises can be categorized into various modalities based on the movement patterns and goals they target

Modality

Upper Extremity. Trainers have developed various exercises for the upper extremities that aim to enhance the impulsive qualities of muscular performance. Examples of upper-extremity plyometric exercises include medicine ball throws, clap push-ups, plyometric push-ups, and rotational throws. Carter et al. (2007) revealed that 8 weeks of upper-extremity plyometric training significantly improved baseball throwing velocity in National Collegiate Athletic Association (NCAA) Division I baseball players. Similar results were found in another study with baseball players (Newton & McEvoy, 1994). The authors suggested the upper-extremity velocity movements and position directly transfer to maximizing the force output with overhead-throwing, as well as eliciting the post-activation potentiation when combined with resistance training. Thus, upper extremity plyometric may be beneficial for developing upper-body power and strength that can improve athletic performance (Turna et al., 2019; Vossen et al., 2000). It is notable that researchers suggested upper and lower plyometric training should not be performed on the same day to limit neural fatigue (Sáez-Sáez de Villarreal et al., 2010; Wathen, 1993).

Trunk. Trunk training can be defined as the musculature around the diaphragm, pelvic floor, abdominals, paraspinals, and gluteal muscles. While there is a lack of plyometric exercises that isolate trunk movements, the trunk is commonly incorporated with lower and upper extremity plyometric exercise. This is particularly true for common plyometric exercises that involve the rotation and anti-rotation of the trunk, such as rotational ball throws, wood chops, power pallof, and press (Chu, 1998). The inclusion of trunk training as a complementary component of sport-specific training is highlighted in a meta-analysis by Saeterbakken et al. (2022), which revealed that trunk training may allow athletes to generate greater maximal power with more efficient use of the lower and upper extremities.

Lower Extremity. Lower extremity plyometric training is typically achieved with reactive or non-reactive jumping skills. Lower body plyometric exercises are any drills used to activate the SSC, with the aim of benefiting strength, muscle power, coordination, and athletic performance (de Villarreal et al., 2009). Examples of lower-extremity training include both bilateral and unilateral vertical and horizontal; hops, skips, jumps, bounds, sprints, and change of directions drills.

Assisted and Resisted Plyometrics. Assisted and resisted training methods have been adapted from sprint training into plyometric training. Assisted plyometrics are performed with the aid of elastic bands to act like a body harness and can be used for jumps, such as the drop jump and countermovement jump. Resisted plyometrics are performed under external load conditions such as water, sand, dumbbells, and adding external load or bands pulling downwards (Khodaei et al., 2017). Ground contact time is an easy way to differentiate between assisted and resisted plyometrics. Assisted plyometrics will result in shorter ground contact time, while resisted plyometrics will lead to longer ground contact times compared to traditional plyometrics (Khodaei et al., 2017).

The idea behind assisted and resisted plyometric training is based on the training principles of specificity and overload. According to a recent meta-analysis, both assisted and resisted plyometric training are equally effective as plyometric methods for improving vertical and horizontal jump performance (Makurak et al., 2020). The authors recommended assisted and resisted plyometric training methods may not be ideal to use with novice athletes or individuals but may be used as an alternative or supplementary training modification to improve power. Resisted plyometric training can be utilized to generate maximal force for jumping performance enhancements. Assisted plyometric training can be used to generate maximal force for increasing jump performance when the amortization phase needs to be as short as possible (Makurak et al., 2020). Additionally, plyometric modalities can be combined within a training program to target different aspects of power and explosiveness.

The choice of modalities should align with an athlete's goals, sport-specific demands, and individual strengths and weaknesses. The fundamental principle of plyometric is the utilization of the stretch-shortening cycle, where a muscle is rapidly stretched (eccentric phase) and immediately followed by a forceful contraction (concentric phase). This quick transition from lengthening to contracting is what leads to enhanced power. Plyometric exercises include activities like jumping, bounding, hopping, and throwing, with variations like box jumps, depth jumps, and medicine ball throws. These exercises are typically characterized by rapid, explosive movements. Plyometric training is a valuable tool for individuals looking to enhance their explosive power and speed. When incorporated into a well-designed training program and performed with proper technique and safety measures, it can help individuals excel in their physical pursuits. Progressing a PT program is a critical component in progressing an individual program, beginners should start with low-intensity plyometric exercises and gradually progress to more advanced movements to avoid overexertion and minimize the risk of injury.

Intensity

Unlike measuring intensity for resistance training programs where a percentage of an individual's one-repetition maximum is used for progress, plyometric intensity can be difficult to measure because it involves multiple variables such as ground contact time, jump height, and power output. Additionally, different joints and muscle groups may be stressed depending on the exercise, making joint-specific measurement important for program design. Despite these challenges, methods for quantifying and categorizing plyometric intensity do exist, including force plate, EMG, and field data.

Force Plate. When using a kinetic quantification lens, Ebben et al. (2011) determined that the critical variables to consider when categorizing plyometric exercises on a spectrum of low to high intensity include ground reaction force at take-off, time to take-off, ground reaction force during landing, and landing rate of force development. If the goal is to increase power and performance during the take-off phase, then plyometric exercise with increased ground reaction force during take-off or decreased time to take-off should be progressively implemented (Ebben et al., 2011). In contrast, if the goal is to improve landing ground reaction forces, then plyometric exercise with increasing ground reaction forces during landing or landing rate of force development should be prioritized in developing the plyometric training protocol (Ebben et al., 2011).

Electromyography. EMG measures the electrical activity of the muscle and is often used to assess the health of muscles and nerve cells. Ebben et al. (2008) established that EMG can be used to assess intensity of specific exercises based on MU recruitment. The methodology included measuring integrated EMG of the gastrocnemius, quadriceps, and hamstrings during a single repetition of hops (two-foot ankle, 15.24-cm cone) and jumps (depth at 30.48 and 61 cm, pike, tuck, single-leg vertical, double-leg vertical, squat with 30% of one-repetition maximum squat, and box) with one minute of rest between each exercise. Ebben et al. (2008) noted their findings differed from anecdotal recommendations regarding plyometric intensity in several ways. For instance, while the depth jump has long been considered the highest intensity form of plyometric exercise, Ebben et al. (2008) found that MU recruitment was highest in the quadriceps when completing cone hops, box jumps, vertical jumps, and tuck jumps, while depth jumps yielded the lowest mean quadriceps EMG. These results contrast previous recommendations by Chu, 1998 that single-leg jumps and depth jumps are the highest intensity plyometric exercise. Similarly, the gastrocnemius EMG measurements were higher during vertical jumps and cone hops than single-leg jumps and depth jumps (Ebben et al., 2008). Furthermore, ankle hops, tuck jumps, and box jumps yielded higher gastrocnemius MU recruitment than 61-cm depth jumps. Ebben et al. (2008) also noted an unexpectedly lower MU recruitment during movements that are single-legged or that had added mass or greater drop distance, which was attributed to increased stretching loads yielding more passive force production. Interestingly, hamstring EMG activity varied too much for analysis between participants based on exercise, which the authors hypothesized was a result of different landing strategies.

As a result of their study findings, Ebben et al. (2008) suggested that a practical approach to evaluating the intensity of plyometric exercises may be classifying them as performance enhancing or pre/rehabilitation based on a set of variables. The authors noted that performance enhancing variables would include rate of force development (concentric, eccentric, and time to takeoff), peak power, MU recruitment, and reactive strength index during the time to takeoff. Variables associated with pre/rehabilitation were noted as ground reaction force, time to stabilization, joint reaction force, and MU recruitment.

In a study conducted by Jarvis et al. (2016), 7 male recreational athletes who were familiar with resistance training and plyometric exercises were assessed through seven plyometric exercises: rebound exercises (rebound jump, 30-cm drop jump, 40-cm drop jump, rebound hop, and step hop) and non-rebound exercise (countermovement jump and hop). Depending on the exercise, rebound or non-rebound exercises can fall in the range of both high and low intensity based on the degree of eccentric muscle activity reached and neuromuscular involvement (Jarvis et al., 2016). These findings indicate MU recruitment for rebound and non-rebound in the concentric phase does not significantly differ if the activity is performed at maximal effort, as well as no differences in mechanical output between unilateral and bilateral plyometric exercises. However, there were high levels of eccentric muscle activity for rebound exercises compared to non-rebound exercises, demonstrating eccentric muscular activity represents an important component of intensity. Factors that could affect eccentric muscle activity include range of motion, foot contact, and joint angle distribution. Jarvis et al. (2016) suggested that monitoring surface EMG during training can provide valuable insights into muscle activation patterns and muscular demands. However, it may not always be practical or feasible due to the equipment and expertise required. In some cases, alternative methods of evaluating exercise intensity, such as measuring peak force, eccentric peak force, and impulse, may be more reliable and easier to implement. Coaches may be best advised to select exercises in which similar joint angle (hips, knees, and ankles) and ground contact time to the action they wish to enhance.

Joint-Specific Mechanical Demand. Another common way to assess plyometric training intensity is to evaluate the mechanical demand placed on a given joint. This may provide a more comprehensive understanding of the intensity of plyometric exercises and allow for the design of rehabilitation protocols based on an individual’s specific injuries. In addition to mindfulness of the joints involved in plyometric exercises, consideration for the complexity of the jump, such as tuck or backwards jumps, may also affect intensity at the joint level (Van Lieshout et al., 2014). Several researchers have investigated the classification of intensity based on load at a given joint.

Van Lieshout et al. (2014) evaluated sum of peak power and joint peak power at the ankle, knee, and hip during various plyometric jumps (forward jump, backward jump, box jump, tuck jump, depth jump) to rank the intensity of each jump in collegiate athletes. Plyometric movements involving horizontal translation in the air (e.g., backward jump, forward jump, tuck jump) produced greater joint-specific intensity (ankle, hip, and knee) compared to movements with little to no horizontal translation (box jump and depth jump). Similarly, Jensen and Ebben (2007) identified differences in eccentric rate of force development among various plyometric jumps in 6 collegiate athletes. The eccentric rate of force development, peak knee joint reaction force, and peak knee joint reaction relative to body weight varied among squat jump, squat jumping holding dumbbells 30% of one- repetition max, and pike jumps. Eccentric rate of force development was significantly less than depth jumps form 46 cm and 61 cm compared to other jumps such as, countermovement jump single leg jump and tuck jump. These differences are possibly due to their relative intensity and landing techniques that are influenced by factors such as jump height, unilateral vs. bilateral landing, and additional external load. Differences were also seen in peak knee joint reaction forces for pike, single leg, and tuck jumps likely due to increases in participants active concentric activation of the knee and hip muscles, thus demonstrating variations in intensity with different plyometric exercises. Plyometric exercises with higher knee joint reaction forces should be presented later into a plyometric program to increase intensity. Coaches and practitioners should consider joint-specific demands when designing plyometric programs. Classifying intensity based on joint-specific demand will give individuals a more precise exercise program.

Rating of Perceived Exertion. The previously mentioned means of assessing PT intensity, particularly EMG or biomechanical markers, are primarily accessible in laboratory settings. While limited research is available on the topic, a tenable and low-cost method that can be applied to large groups of varying plyometric experience intensity is the Borg Rating of Perceived Exertion (RPE) scale (6-20; Borg, 1982; Khodaei et al., 2017). Plyometric activities such as jumping and sprinting may have a relationship with RPE and intensity due to multiple factors, such as skeletal muscle activation, metabolic demand, and neurological factors that might affect fatigue (Asadi, 2014; Gearhart et al., 2001; Lockie et al., 2011).

According to Asadi (2014), the motor cortex must send a stronger signal to the sensory cortex to achieve greater MU recruitment, which would result in an increased perception of effort. Further, Khodaei et al. (2017) observed 20 college-age amateur male soccer players as they performed nine plyometric exercises for 10 repetitions and rated the intensity on the Borg RPE scale (6-20), ranking each exercise as light (6-10), moderate (11-14), or high intensity (15-20). Jumps with low barriers, bilateral jumps, and low impact-related jumps (cone hops, squat jump) were considered light intensity. Jumps that had high landing forces and high rate of force development were considered moderate or high intensity (broad jump, box jump, depth jump). Plyometric exercises that were deemed high intensity were ingle-leg variations (box jump, broad jump, depth jump).

It should be noted that using the Borg scale to determine the intensity of plyometric drills for single session use or programing may take time because everyone's experience level and intent during exercise differs. Coaches and practitioners must be mindful when altering plyometric exercises for the purpose of increasing intensity because they may concurrently be altering take-off and landing forces. Examples of ways to increase intensity determined by RPE include changing bilateral exercises into unilateral exercises, increasing box height, increasing drop height, increasing the complexity of the exercise, and changing surface area. Additional research needs to go more in depth about PT programs that use RPE to measure intensity across multiple sets and timepoints in a training program.

Measuring plyometric exercise intensity can be difficult due to multiple variables. When evaluating plyometric intensity through force plate, EMG, joint-specific demand, or RPE intensity should be progressively increased over time to avoid overexertion and reduce the risk of injury. Understanding and managing intensity is crucial for achieving individual training goals. Like intensity, training volume represents the total amount of work performed, including the number of repetitions and sets. Managing training volume is crucial to ensure that PT is effective, safe, and aligned with an individual's fitness goals and readiness.

Volume

As with most forms of training, one important programming consideration with PT is volume. Training volume is regularly quantified as the number of foot contacts per training session. Potach & Chu (2008) have recommended 80 to 100, 100 to 120, and

120-to-140-foot contacts per training session for those with beginner, intermediate, and advanced experience, respectively. When comparing low and high foot contact training protocols, researchers have observed similar improvements in a variety of performance outcomes (Jeffreys et al., 2019; Yanci et al., 2016; Yanci et al., 2017). Jeffreys et al. (2019) found that both low (480) and high (1920) foot contacts produced similar increases in reactive strength and leg stiffness. In accord, Yanci et al. (2016) demonstrated 180- and 360-foot contacts per session yielded no difference in horizontal power improvement. In a later study, Yanci et al. (2017) deemed that if weekly foot contacts remain similar (96-176/wk.) then similar increases in performance outcomes would occur in vertical and horizontal power development, reactive strength, and sprint performance.

Aside from the representation of training volume in foot contacts alone, researchers will often combine frequency and volume (number of training sessions per week and total number of training sessions) when discussing program volume. Sole et al. (2021) conducted a meta-analysis and suggested plyometric programs designed to improve jump performance, speed, change of direction, and strength should include a minimum volume of at least 10 weeks, with at least 20 sessions, and between 50 and 240 jumps in each session.

Performing PT programs that exceed an individual's training volume threshold will not lead to increased jump performance and may lead to increased susceptibility to overuse injuries. Therefore, training volume and intensity should be individualized based on an athlete's training history and injury status. Coaches looking to create PT programs should strive for the optimal training efficiency to help reduce overuse injuries and should be cautious when increasing the number of foot contacts within a program, particularly in consideration of the evidence that higher foot contacts does not yield greater improvements in athletic performance (de Villarreal et al., 2008; Ebben et al., 2014; Jeffreys et al., 2019; Yanci et al., 2016).

Recovery

In considering recovery within a single session of PT, a work to rest ratio of 1:5 to 1:10 is recommended, which depends on the intensity of the exercise (Chu, 1998). When considering rest between sessions, high intensity PT sessions should be separated by 48 to 72 hours due to the high potential for post-training fatigue (Haff & Triplett, 2021). Watkins et al. (2020) found that training above 100 jumps per session caused up to a 20% decrease in jump performance due to increased muscle damage and soreness up to 5 days post-training. In accord, Ebben et al. (2014) noted participants need more than 2 days between sessions for recovery, with 6 to 14 days being optimal for individuals participating in other forms of sport. Similarly, Cadore et al. (2013) found that with 100, 200, and 300 contact sessions, neuromuscular performance was acutely impaired for 24 hours. Interestingly, the same study indicated an 8-hour window of post activation potentiation benefit following the training, with the 100-contact session being sufficient to produce this effect (Cadore et al., 2013). Overall, the study provides valuable insights for practitioners designing PT programs. With as little as 100 jumps per session providing sufficient stimulus in neuromuscular, metabolic, and hormonal system. However, it is important to note that plyometric exercises can acutely impair neuromuscular function leading to a decrease in force, power, and rate of force development. This impairment may be due to central and peripheral mechanisms of fatigue. Coaches and practitioners should carefully monitor the volume within a training cycle. Individuals may not be able to perform strength or power activities at their best within the first 24 hours after PT.

Adequate rest between PT sessions is essential. The intensity of these workouts places a significant demand on the muscles and central nervous system. Typically, 48-72 hours of recovery between sessions is recommended. With any PT program proper progression is vital to ensure that PT is effective, safe, and aligned with an individual's fitness goals and capabilities.

Progression

When considering progression of PT programs, there is evidence that programs with and without built-in progression can increase power (vertical and horizontal), agility, speed, and endurance when compared to a control group (Palma-Muñoz et al., 2021; Ramírez-Campillo et al., 2015). However, both authors demonstrated the groups that progressively increased their volume saw more significant improvements in several measures of athletic performance, including jumping (vertical jump, horizontal jump), agility (T-test), sprint performance (10-meter) and endurance (Yo-Yo). The simple training principle of progressive overload can more effectively enhance neural drive to the agonist muscle, improve intermuscular coordination, and alter muscle-tendon mechanical stiffness characteristics (Palma-Muñoz et al., 2021; Ramírez-Campillo et al., 2015).

Coaches and practitioners looking to progress PT over time in the form of increasing volume should start at a low (50-100 jumps) but effective training volume then progress according to the individual's needs to avoid overtraining and injury (Palma-Muñoz et al., 2021; Ramírez-Campillo et al., 2015). Currently there is a lack of literature on the exact recommendations for plyometric volume progressions, coaches and practitioners should also be mindful that increasing volume may indicate a need to increase between-session recovery time (Palma-Muñoz et al., 2021).

Proper recovery and rest is essential to allow the body to repair and adapt to the demands of plyometric exercise. Potentially performing PT on different surfaces may promote distinctive adaption.

Surface

Aquatic. Traditionally PT is performed on land with the expected outcome of significant increases in power. However, PT on land is also associated with muscle damage and muscle soreness due to the intensive ground impact forces during the landing phase. Most training injuries, such as meniscal damage, knee tendonitis, Achilles tendon strains, and heel bruises have been linked to repetitive plyometric movements (Miller et al., 2002; Robinson et al., 2004). As such, modifying training to expose participants to less impact would be beneficial if training adaptations can be maintained. One proposed modification to accomplish this is completing PT in the water.

When observing land-based and aquatic-based PT, there are differences in the amount of force produced and force applied during each phase. Because of buoyancy forces of water, the loading and landing phases of aquatic plyometrics elicit reduced compressive forces to lower body joints and connective tissue. Plyometric training in aquatic environments allows buoyancy to decrease an individual's weight causing reduced pressure placed on the musculoskeletal system, allowing for a more comfortable landing phase compared to land training (Arazi & Asadi, 2011; Miller et al., 2002; Stemm & Jaconson, 2007). Thus, one expected outcome of aquatic PT is a reduced risk of injury and muscle soreness (Gulick et al. 2007; Miller et al., 2002; Robinson et al., 2004). Furthermore, the decrease of force decreases the amortization phase, allowing a swifter concentric action (Miller et al., 2002). In addition to potential for injury prevention with aquatic-based plyometrics, the theory for yielding training adaptations is that the density of water causes an increased resistance to movement, requiring increased muscle activation (Robinson et al., 2004).

Plyometric training on either land or in an aquatic environment enhanced vertical and horizontal jump performance (Arazi & Asadi., 2011). Different training environments will elicit lower body power development by differing mechanisms. Training in water provides higher velocity with lower load and faster transition time, while training on land provides greater strength due to heavier load on the joints and connective tissue. (Arazi & Asadi, 2011; Robinson et al., 2003; Stemm & Jacobson, 2007). For both land and aquatic based PT, research has shown mixed results between groups and power production. Miller et al. (2002) and Robinson et al. (2004) performed similar 8-week land versus aquatic training groups including recreational male and female athletes, where both groups exhibited significant improvement in vertical jump performance. Similarly, investigations of athletic participants indicated similar, significant increases in power and jumping performance following land and aquatic PT (Stemm & Jacobsen, 2007; Villarreal et al., 2015). Miller at al. (2002) further explained the increase in power development with aquatic training comes from the decreased transition time, whereas the land-based training group experienced longer transition phase times with more force being absorbed during the eccentric or landing phase. In contrast, Gulick et al. (2007) performed a 6-week land versus aquatic plyometric program with untrained males and females, finding the aquatic group significantly increased vertical jump power compared to the control and land groups. The contrasting results of these studies are likely due to the training status of participants, where untrained persons benefit more from the water training while trained persons can equally benefit from land or water training. This could be due to neurological adaptions developing faster in an aquatic environment compared to a land-based environment, as well as the potential for participants to feel more comfortable performing plyometrics in water, allowing them to give a higher intensity of effort.

Plyometric training in an aquatic environment offers several unique benefits due to the properties of water as a resistance medium. Utilizing an aquatic environment can reduce impact and stress on joints, lower overuse injuries, enhance muscle strength, and be use during recovery and rehabilitation. However many individuals may not have access to an aquatic training facility, but can still perform PT on either hard or soft surfaces.

Non-Rigid versus Rigid Surfaces. Plyometric training on different surfaces may yield different neuromuscular and stretch-shortening adaptations (Elvan et al., 2019). For example, when training on a non-rigid surface, the surface area yields differential adaptations including increased nerve conduction velocity, improved intermuscular coordination, enhanced MU recruitment, and increased excitability of the Hoffman reflex (Prieske et al., 2013). One example of a non-rigid training surface is sand, which allows shock absorption and reduced stress on the musculoskeletal and connective tissues while adding the challenge of lower stability and hindering the stretch-shortening cycle. More specifically, the amortization phase is increased when performing PT in the sand, which decreases the myotatic reflex and elastic energy (Mirzaei et al., 2013). This reduction in elastic energy, in conjunction with changes in jump kinematics, requires an increase in muscle fiber activation (Mirzaei et al., 2013).

As a result of these physiological changes, there is evidence that PT in the sand yields similar, if not greater improvements in strength, power, speed, and agility when compared to a more ridged surface (Ahmadi et al., 2021; Arazi et al., 2014; Mirzaei et al., 2013; Nagaraja & Gajanana Prabhu, 2017; Ozen et al., 2020; Resh et al., 2017). The samples for these studies included highly trained youth male basketball players (Ozen et al., 2020), elite male volleyball players (ÖZ et al., 2019), recreational female volleyball players (Ahmadi et al., 2021), healthy young men who were familiar with PT (Arazi et al., 2014), national-level male volleyball players (Resh et al., 2017), intercollegiate recreational athletes (Nagaraja & Gajanana Prabhu, 2017; Singh et al., 2014), recreational male basketball players (Mankar, 2020), and elite male volleyball players (Elvan et al., 2019). The training durations were two (Resh et al., 2017), 4 (Singh et al., 2014), 6 (Arazi et al., 2014; Mirzaei et al., 201; Ozen et al., 2020), 7 (Hammami et al., 2020), 8

(Ahmadi et al., 2021; Elvan et al., 2019; Nagaraja & Gajanana Prabhu, 2017; Öz et al., 2019), and 12 (Mankar, 2020) weeks. For training volume all above authors trained two days per week with at least 48 hours between sessions, and total number of contacts ranged between 50-160 ground contacts per training session. Additionally, all but two of the previously mentioned samples trained on sand, while two samples used a foam balance pad for the non-rigid surface (Öz et al., 2019; Prieske et al., 2013).

When comparing adaptations to PT on rigid and non-rigid surfaces, some researchers reported greater increases in a variety of performance measures following both short-term (2 weeks; Resh et al., 2012) and long-term (6 to 12 weeks; Mankar, 2020; Nagaraja & Gajanana Prabhu, 2017;) PT in the sand when compared to a land surface. There were greater improvements in vertical jump (Resh et al., 2017), speed (Mankar 2020; Resh et al., 2017), agility (Resh et al., 2017; Singh et al., 2014), and lower body power (Mankar, 2020). In contrast, other investigators indicated similar improvements between land and sand training, including strength (Nagaraja & Gajanana Prabhu,2017; Singh et al., 2014), lower body power (Nagaraja & Gajanana Prabhu., 2017), speed (Arazi et al., 2014; Nagaraja & Gajanana Prabhu, 2017; Ozen et al., 2020; Öz et al., 2019; Singh et al., 2014), vertical jump (Ozen et al., 2020), horizontal jump (Ozen et al., 2020), and agility (Arazi et al., 2014; Nagaraja & Gajanana Prabhu, 2017; Ozen et al., 2020; Öz et al., 2019). Furthermore, while not all studies measured muscle soreness, it is notable that Resh et al. (2017) reported similar muscle soreness ratings for those who completed training in the sand compared to those who completed land training.

The observed improvement in performance measures when comparing training on non-rigid and rigid surfaces is not clear and may be influenced by a multitude of variables, such as program duration, training volume, rest interval, intensity, sport and participant characteristics. Furthermore, performance outcome measurements might be individually determined by the athlete's ability to adapt to stimuli. Looking at the frequently measured outcomes, training on a non-rigid surface was most likely to yield greater improvements in speed and/or agility (Mankar, 2020; Resh et al., 2017), although most researchers reported improvements of similar magnitude for each of the measured outcome variables (Ahmadi et al., 2021; Arazi et al., 2014; Nagaraja & Gajanana Prabhu, 2017; Ozen et al., 2020; Öz et al., 2019).

Regarding agility and speed training, a non-rigid surface may be more beneficial due to an unstable surface causing an increase in lateral movement and amortization time, making it more difficult for the body to move through the vertical axis and allowing the muscles to absorb more force while relying on fewer elastic properties seen in the SSC (Arazi et al., 2014; Hammami et al., 2020; Singh et al., 2014). These unique attributes of sand training are expected to yield specific adaptations, including quicker muscle action and a more effective eccentric to concentric transition, allowing the stretch reflex to increased power in sprinting and agility (Arazi et al., 2014; Hammami et al., 2020; Prieske et al., 2013). While all researchers note participant's previous experience with PT or non-rigid surface training, this could have been contributing factors to the disparate findings among studies.

It is notable that while training on a non-rigid surface did not necessarily exceed the benefits of training on a rigid surface, there is no evidence of non-rigid surface training hindering performance on any of the measured parameters. It is reasonable to extrapolate that the studies where change was experienced at a similar magnitude across training surfaces can be explained by differential sources of adaptation. For example, the lack of significant differences in jump performance between ridged and non-ridged surfaces in some studies may be because both surfaces can improve jump performance, but through different mechanisms (Ahmadi et al., 2021). Plyometric training on a non-ridged surface, such as sand, may place a greater emphasis on the muscular system due to the higher level of physiological strain, leading to increased mechanical work and strengthening in the musculotendinous junction (Ahmadi et al., 2021; Öz et al., 2019). Alternatively, training on a ridged surface may place greater emphasis on the neural system, which enhances neural drive and MU recruitment (Elvan et al., 2019). Overall, both surfaces contributed to an increase in positive energy production, either during the eccentric phase by utilizing the recoil of elastic energy stored in the stretch-shorting cycle found on rigid surfaces or during concentric action due to increased muscular strength found on non-ridged surfaces (Ahmadi et al., 2021; Elvan et al., 2019; Öz et al., 2019).

Overall, training on either a ridged surface (hardwood) or non-ridged surface (sand) seems to yield at least similar improvements in jump performance and strength. Based on the available literature, there are no clear protocols or sample characteristics that allow researchers or practicing professionals to predict the efficacy of sand versus land training. Further research is warranted in this area. Nevertheless, sand’s absorptive and unstable properties may yield increases in lateral movement and challenges to balance not seen with more stable surfaces. This causes an increase in neuromuscular adaptations and strength within the muscles involved in balancing, thus enhancing the training response when transitioning to firm ground. Coaches using PT must specify the goals for the training session or training cycle. If the goal is to improve jump performance for sports such as high jump for track or volleyball, training on land or sand will likely yield similar improvements. However, if the goal is to reduce ground contact time and increase agility and speed in sports such as football and soccer, then performing PT on non-rigid surfaces, such as sand, are more beneficial than training on traditional ridged surfaces.

Summary

Overall, the literature indicates PT enhances both the central and peripheral nervous system in a coordinated manner to improve motor control, coordination, and the ability to generate force. Neural adaptions are important for individuals seeking to enhance their athletic capabilities (Chu, 1998). When designing a PT program, it is important to consider a variety of plyometric modalities that can target different aspects of performance such as altering training surface and volume. Research is warranted in further examining the effects of training surface and plyometric volume training on their effects on lower body power development. The vast majority of investigation on this topic has focused on athletic populations, with less information about the effect of PT surface and volume on college-aged, recreationally active individuals. By studying this population, investigating lower body power development can contribute to the advancement of individualized exercise recommendations Therefore, the purpose of the studies in this dissertation is to investigate how PT surface and training volume effects static and dynamic jump performance affect college-aged, recreationally active individuals.

CHAPTER III

THE EFFECTS OF SURFACE COMPOSITION ON VERTICAL JUMP PERFORMANCE DURING A 6-WEEKS PLYOMETRIC TRAINING PROGRAM

Introduction

The ability to generate power in the sagittal plan is an important component in sports such as basketball and volleyball (Nagaraja et al., 2017). Plyometric training (PT) is a popular training modality to increase vertical power (Ramirez-Campillo et al., 2018). During PT, an eccentric pre-stretch and shortened amortization phase in the stretch-shortening cycle (SSC) activate the stretch reflex, contributing to a more forceful concentric contraction (Peitz et al., 2018). Initially, plyometric research predominantly involved elite or extensively trained athletes. While this research offered crucial insights into the advantages and potential drawbacks of PT, applying these findings directly to physically active individuals (PAI) is not necessarily straightforward. People engaged in physical activity encompass a broad range of fitness levels, ages, and training backgrounds. Designing studies that capture this diversity can be challenging, and researchers may prefer to focus on more homogeneous groups to draw clearer conclusions.

PT is typically performed on a hard surface like a gymnasium floor. However, PT can also be performed on softer surfaces such as grass, sand, and foam mats, as well as in water. PT on soft surfaces absorb force and reduce stress on the musculoskeletal system while challenging lower limb stability and increasing the amortization phase (Ramirez-Campillo et al., 2020), ultimately requiring increased muscle fiber activation because of lower elastic energy (Mirzaei et al., 2013). Ramirez-Campillo et al. (2013) documented the impact of training surface on the SSC in adolescent high school males. Moderate volume PT on hardwood provided the best stimulus for improving fast SSC performance (drop jump), while PT on a foam mat improved slow SSC performance (squat jump) and agility (Rameriz-Campillo et al., 2013). PT on hard or soft surfaces may also alter the training-induced effects for vertical jump performance. PT on hard surfaces appears to be superior in enhancing dynamic jumps (counter movement jump, approach jump) while PT on soft surfaces appears to be superior in enhancing static jump (Impellizzeri et al., 2007; Ozen et al., 2020). There is a lack of research diversity on PT on different surfaces and their effect on vertical jump performance. A broader understanding of PT modalities and performance outcome can assist individuals and professionals tailoring PT programs to meet the specific needs and capabilities of given populations, making exercise more effective.

Beyond performance outcomes, there is evidence that training on softer surfaces yields lower muscle soreness and/or muscle damage for amateur male and female soccer players (Impellizzeri et al., 2007; Miyama & Nosaka, 2004). Miyama and Nosaka (2004) observed lower self-reported muscle soreness (0 to 100 visual analog scale) and plasma creatine kinase concentration immediately after and 1, 24, 48, 72, and 96 hours following 20 consecutive drop jumps on sand compared to hardwood. Further, Impellizzeri et al. (2007) observed lower self-reported muscle soreness (7-point Likert scale) when training in sand. Investigating performance outcome measurements with PAI can provide insight that can be directly applied to everyday training and fitness routines, that has more practical relevance and more relatable for individuals who are not elite athletes.

Although previous research has investigated the effects of PT on various surfaces, these studies have primarily focused on high school or elite athletic populations, leaving the impact of training surface on PAI unknown. Utilizing PAI as subjects for this study is justified, considering the extensive impact it could have on health, performance, injury prevention, and the optimization of exercise programs for a diverse population. The results of this research carry practical implications for individuals seeking to enhance their physical fitness and performance.

It is important to understand how alternative training surfaces can be utilized to optimize specific adaptations and minimize muscle soreness or injury in a manner that is accessible to varying populations. Therefore, the purpose of this study was to compare the effects of a 6-week PT program on a hard or soft surface on changes in vertical lower body power assessed by; squat jump (SJ), countermovement jump (CMJ), and approach jump (AJ) performance in PAI. It was hypothesized that performing PT on a soft surface would increase SJ performance compared to hard surface. It was also hypothesized that performing PT on a hard surface would increase the heights of the CMJ and AJ performance compared to a soft surface.

Methods

Study Design

This was an experimental study approved by the Middle Tennessee State University Institutional Review Board (IRB Approval #: 21-2173 4i; see Appendix A).

The dependent variables were squat jump (SJ), countermovement jump (CMJ), and approach jump (AJ) heights, while the independent variable was training surface (soft or hard). G*Power (verision 3.1.9.4) was used to calculate a priori sample size for the within-between interaction of a 2x2 repeated measures ANOVA. The recommended sample size was 8 participants per group to have power of .80, assuming a medium effect size and correlation of .80 among the repeated measures.

Participants

All 18 participants, 10 males and 8 females, participated were recruited by word of mouth from a university community in the Southeastern United States (see Appendix E). All volunteers read and signed the informed consent prior to participation (see Appendix C). To be included in the sample, participants needed to be physically active by participating in aerobic or anaerobic exercise at least 30 minutes per session, 3 days a week, for the past 3 months (Liguori et al., 2021), free from lower limb musculoskeletal injuries within the past 6 months, and not actively participating in any PT program. This information was obtained with physical activity, PT, and lower limb musculoskeletal injury surveys (see Appendix D).

Participants were randomly assigned to soft and hard training groups while counterbalancing group placement by sex. The soft surface training group included 5 males and 4 females (mean age: 20.3 ± 1.7 year; body mass 67.1 ± 7.2 kg; height 1.7 ± 0.1 m), while the hard surface training group included 5 males and 4 females (mean age: 22.1 ± 5.6 year; body mass 72.3 ± 16.8 kg; height 1.7 ± 0.1 m).

Materials and Procedures

During the initial session participants read and signed the informed consent and completed the surveys to assure they met the inclusion criteria. Participants were instructed to wear athletic attire for all testing and training sessions. Body mass was measured using a digital scale (Tanita, Arlington Heights, IL, USA) and height was measured using a stadiometer (SECA 222, Chino, CA, USA). Participants' second session was their pre-test. During pre-test participants completed a warm-up consisting of 10 repetitions of: jump rope, air squats, ankle hops, and countermovement jumps at a self-selected intensity with a 1-minute rest between each exercise. Following the warm-up, participants rested for 2 minutes, during which instruction was given to the participants on how to perform each jump (SJ, CMJ, and AJ).

For the SJ, participants were instructed to set their feet hip width apart, squat into a semi-squatted position, and hold that position (3-5 seconds) with the arm pulled back to the side. On a cue from the primary investigator, participants were instructed to maximally engage their leg muscles and explode upward with arms raised above the head without any countermovement. For the CMJ, participants were instructed to set up in the same initial manner as the SJ jump, then quickly squatting down to a self-selected depth while pulling the arms back, and rapidly ascending into the air while throwing the arms overhead. For the AJ, participants were instructed to take a 3-step approach (left, right, left or right, left, right) to act as a breaking mechanism to convert the horizontal momentum into vertical propulsion. For all jumps, participants were instructed to perform each attempt using a bilateral stance for both take-off and landing, while swinging their arms and bending their knees approximately 90 to 110 degrees to provide maximal vertical propulsion (Ducharme et al., 2016; Wakai & Linthorne, 2005). Prior to pre-testing, participants performed three submaximal SJ, CMJ, and AJ with an arm swing. The assessment sequence for all testing sessions was SJ, CMJ, and AJ, with 30 seconds between each jump until no improvement in performance was achieved and a 2 minute break between the different types of jumps. The best trial, recorded to the nearest half inch, was used in data analysis and all testing trials were completed on a hardwood surface, and measured using a Vertec™ Vertical Jump Trainer (Sports Imports, Worthington, OH, USA).

The hard surface training group conducted their training regimen on a solid wood gymnasium floor, while the soft surface training group utilized a 2-inch-thick wrestling mat placed on top of the gymnasium floor. Participants performed a 2-week accommodation period to become familiarized with the training program. During this period, participants completed the first two weeks of the training program, allowing them to acclimate to the training requirements and receive instructions on proper form and technique. Following the 2-week accommodation period pre-testing was conducted. After the pre-testing, the 6-week training program began. Following completion of the 6-week training program participants underwent their post-test 24-72 hours after their last training session. The testing procedures for the post-test mirrored those of the pre-test.

Training Protocol

For the duration of the study, participants agreed to maintain current exercise habits. Each training group performed an identical mixture of plyometric exercises designed to increase lower body power (see Table 1), with the only difference being training surface. The PT program that was used in the current study was developed by Miller et al. (2007) and Sozbir et al. (2016). All participants performed two supervised training sessions per week separated by at least 48 hours for a total of 12 training sessions. Participants were allowed to miss two training sessions throughout the program. Each session began with a warm-up that consisted of standing long jumps and ankle hops that covered 25 meters in distance, followed by 10 CMJs. Participants performed the warm-up on the same surface as assigned for training. During each training session, a 30-second break was taken between each set and a 1-minute break occurred between each exercise. The duration of each session ranged from 20 to 40 minutes.

Statistical Analysis

The mean differences for SJ, CMJ, and AJ were compared using three 2 (Surface: soft and hard) x 2 (Time: pre-test and post-test) repeated measures ANOVAs. An alpha level of $p \leq .05$ was used to determine statistical significance. Effect sizes were reported as partial eta squared (η_p^2) and Cohen's *d* (calculated as $(Mean_2 - Mean_1) / SD_{\text{pooled}}$) for the ANOVAs and mean differences, respectively. All statistical analyses were completed using IBM SPSS v. 29 (Armonk, NY, USA). Means and standard deviations for all conditions are shown in Table 2. There were no instances of dropout or injury recorded throughout the duration of the study.

Results

Squat Jump

The results of the repeated measures ANOVA for SJ indicated no significant 2-way interaction ($F_{1,16}$ = 0.51, p = .484, η_p^2 = .03) and no significant main effect for surface ($F_{1,16}$ = 0.17, p = .686, η_p^2 = .01). There was a significant main effect for time ($F_{1,16}$ = 38.19, p < .001, η_p^2 = .71, d = 0.53; see Table 2).

Counter-Movement Jump

The results of the repeated measures ANOVA for CMJ indicated no significant 2-way interaction ($F_{1,16}$ = 0.41, p = .530, η_p^2 = .03) and no significant main effect for surface ($F_{1,16}$ = 0.48, p = .499, η_p^2 = .03). There was a significant main effect for time ($F_{1,16}$ = 56.14, p < .001, η_p^2 = .78, d = 0.33; see Table 2).

Approach Jump

For the AJ, the results of the repeated measures ANOVA indicated no significant 2-way interaction ($F_{1,16}$ = 0.76, p = .398, η_p^2 = .05) and no significant main effect for surface ($F_{1,16}$ = 0.73, p = .406, η_p^2 = .044). There was a significant main effect for time ($F_{1,16}$ = 29.36, p = .001, η_p^2 = .65, d = 0.36; see Table 2).

Table 1

6-week Plyometric Training Program Protocol

Week	Volume (Foot Contacts)	Plyometric Exercises	Sets x Reps
1	90	Lateral ankle hops*	2 x 15
		Counter-movement jump*	2 x 15
		Front barrier jumps*	5 x 6
2	120	Lateral ankle hops*	2 x 15
		Standing long jump*	5 x 6
		Lateral barrier jumps**	2 x 15
		Tuck jumps**	5 x 6
3	120	Lateral ankle hops*	2 x 12
		SLJ*	4 x 6
		Lateral barrier jumps**	2 x 12
		Tuck jumps**	3 x 8
		Lateral barrier jumps**	2 x 12
4	140	Diagonal barrier jumps*	4 x 8
		Standing long jump with lateral sprint**	4 x 8
		Lateral barrier jumps**	2 x 12
		Single leg bound***	4 x 7
		Side to side unilateral jumps***	4 x 6
5	140	Diagonal barrier jumps*	2 x 7
		Standing long jump with lateral sprint**	4 x 7
		Lateral barrier jumps**	4 x 7
		Barrier jumps with half turn**	4 x 7
		Single leg bound***	4 x 7
		Side to side unilateral jumps***	2 x 7
6	120	Diagonal barrier jumps*	2 x 12
		Hexagon drill*	2 x 12
		Barrier jumps with directional sprints**	4 x 6
		Tuck jumps**	3 x 8
		Side to side unilateral jumps***	4 x 6

Note. * = low intensity; ** = medium intensity; *** = high intensity.

Table 2. *Descriptive statistics for surface condition jump height (cm).*

	Soft Surface		Hard Surface		All Surfaces	
Variable	Mean	SD	Mean	SD	Mean	SD
Squat jump*						
Pre	48.6	10.7	52.6	9.8	50.6	10.3
Post	53.3	12.7	56.7	11.1	55.0*	11.9
Post-Pre	4.7		4.1			
All Times	51.0	11.7	54.7	10.4		
Counter-movement jump*						
Pre	53.9	14.0	58.2	10.0	56.0	12.0
Post	57.3	14.5	61.0	10.1	59.1*	12.3
Post-Pre	3.4		2.8			
All Times	55.6	14.2	59.6	10.0		
Approach jump*						
Pre	56.1	14.0	60.8	11.4	58.5	12.7
Post	59.1	15.1	65.0	11.8	62.1*	13.5
Post-Pre	3.0		4.2			
All Times	57.6	14.5	62.9	11.5		

Note. *Post-test jump height significantly greater (p < .05) than pre-test jump height.

Discussion

The purpose of this study was to compare the impact of training surface on adaptations to 6-weeks of PT. The outcomes assessed included SJ, CMJ, and AJ and the training surfaces included a soft surface (2-inch wrestling mat) and a hard surface (hardwood gymnasium floor). Although there were no significant differences in outcome variable improvement based on surface, both groups exhibited statistically significant enhancements in VJ performance following soft surface training and hard surface training.

In accordance with previous studies on athletic populations, both the hard and soft surface groups demonstrated comparable enhancements in SJ, CMJ, and AJ (Arazi et al., 2014; Öz et al., 2019; Ozen et al., 2020; Ramírez-Campillo et al., 2013; Resh et al. 2017). Assessing a non-athletic population in the current study broadens the scope of applicability for PT beyond sports performance enchantment for athletes. In addition to statistical significance, it is important to consider the practical significance of PAI enhancing their jumping performance. Improvements in jumping hold importance that reaches beyond athletic endeavors including injury prevention, functional fitness, rehabilitation, and overall well-being (McKinlay et al., 2018) . In the current study, it's crucial to recognize the significance of the mean differences, particularly when considering baseline performance, training objectives, and individual variability. PAI increased SJ by 4.1 and 4.7 cm, CMJ by 2.8 and 3.4 cm, and AJ by 4.2 and 3.0 cm following the PT program on hard and soft surfaces, respectively (see Table 1). The increase in jump performance is notable to practitioners. Additionally, it is important to consider baseline performance when establishing the practical significance of the findings. For example, considering that baseline VJ measurements at pre-test were classified as "very good" or "excellent" (Liguori et al., 2021) for participants in the current study, observing an increase of this magnitude is particularly meaningful. Physically active individuals can utilize this information to integrate a PT program into their exercise regimen, which may yield similar improvements in jumping performance as seen in the current study. Further, future researchers who build upon the findings of this study could further develop evidence-based guidelines for diverse populations

The similar improvements in performance following PT on both surfaces suggests the PT program plays a primary role in enhancing VJ performance, regardless of training surface (Ozen et al., 2020). In general, adaptations to PT include increased motor unit function that reflects enhancements in the neuromuscular system's ability to recruit, coordinate, and fire rate motor units, leading to improved muscle function and performance. As well as suppression of antagonist muscles, increased activation and co-contraction of synergistic muscles, and optimization of the SSC (Arazi et al., 2014; Ozen et al., 2020; Ramirez-Campillo et al., 2013). While not assessed in the current study, the basis of VJ improvement may vary by training surface. Training on soft surfaces extends the amortization phase, facilitating greater muscle fiber activation (Mirzaei et al., 2013), effectively improving maximal concentric strength and slow SSC muscle actions (Ramírez-Campillo et al., 2013). In contrast, PT on a hard surface promotes the utilization of stored elastic energy (Mirzaei et al., 2013), enhancing maximal dynamic strength and fast SSC muscle actions (Ramírez-Campillo et al., 2013).

Contrasting the findings of the current study, Ahmadi et al. (2021) did not detect significant improvement in dynamic fast SSC muscle actions (spike jump or AJ) following 6-weeks of PT on either a soft (sand) or hard (wood) surface. One potential reason for this is the participants were female volleyball players and accustomed to performing spike jumps and AJ. Additionally, there may have been measurement limitations, as the participants were hitting a volleyball at a set height and tracking jump height using a motion tracking device potentially leading to skill of hitting a volleyball being the primary task instead of the jump (spike jump or AJ) being the focus. Future research should continue to examine the influence of PT training surface on adaptations to VJ performance with diverse samples, as well as expanding knowledge of the underlying mechanisms and histological changes incurred.

While the present study did not assess PT on a combination of surfaces Ramirez-Campillo et al. (2020) discovered that among male youth soccer players, an 8-week midseason PT program conducted on various surfaces including grass, dirt, sand, gymnasium flooring, and track fields elicited more significant improvements in vertical jump performance compared to a program conducted on a single surface. The use of various training surfaces could provide greater stimulating and reduce monotony during training sessions. This in turn could potentially encourage individuals to exert more effort during training. This variation in training surfaces may also lead to diverse adaptions in the SSC. The current study still has limitations. The lack of kinematic and kinetic data limits the capacity to identify potential mechanisms driving SSC enhancement. Future research should continue to investigate the physiological effects of combining different plyometric surfaces in training, and the impact on VJ performance using kinematic and kinetic measurement tools.

Conclusion

For the SJ, CMJ, and AJ, the current findings showed similar increases in jump height regardless of training surface. These findings suggest vertical power development is not primarily influenced by the training surface. Therefore, it is recommended when designing PT programs, practitioners should prioritize individual's goals and take into consideration both training surface preference and training surface availability. Future research should continue to examine underlying neuromuscular adaptations and biomechanical analysis of PT performed on different surfaces and how that may affect vertical power development.

Chapter III References

Ahmadi, M., Nobari, H., Ramirez-Campillo, R., Pérez-Gómez, J., Ribeiro, A. L., & Martínez-Rodríguez, A. (2021). Effects of plyometric jump training in sand or rigid surface on jump-related biomechanical variables and physical fitness in female volleyball players. *International Journal of Environmental Research and Public Health*, *18*(24), 13093. https://doi.org/10.3390/ijerph182413093

Arazi, H., Mohammadi, M., & Asadi, A. (2014). Muscular adaptations to depth jump plyometric training: Comparison of sand vs. land surface. *Interventional Medicine and Applied Science*, *6*(3), 125–130. https://doi.org/10.1556/imas.6.2014.3.5

Öz, E., Çelenk, B., Hayirli, Özkan, & Öz, E. (2019). The effect of eight-week plyometric training on agilty in male volleyball players. *The Online Journal of Recreation and Sport*, *8*(1), 23–32. https://doi.org/10.22282/ojrs.2019.44

Impellizzeri, F. M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S., & Wisloff, U. (2007). Effect of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *British Journal of Sports Medicine*, *42*(1), 42–46. https://doi.org/10.1136/bjsm.2007.038497

Jensen, R. L., & Ebben, W. P. (2007). Quantifying plyometric intensity via rate of force development, knee joint, and ground reaction forces. *The Journal of Strength and Conditioning Research*, *21*(3), 763. https://doi.org/10.1519/r-18735.1

Katkat, D., Bulut, Y., Demir, M., & Akar, S. (2009). Effects of different sport surfaces on muscle performance. *Biology of Sport*, *26*(3), 285–296. https://doi.org/10.5604/20831862.894793

Lamas, L., Ugrinowitsch, C., Rodacki, A., Pereira, G., Mattos, E. C. T., Kohn, A. F., & Tricoli, V. (2012). Effects of strength and power training on neuromuscular adaptations and jumping movement pattern and performance. *Journal of Strength and Conditioning Research*, *26*(12), 3335–3344. https://doi.org/10.1519/jsc.0b013e318248ad16

Lesinski, M., Prieske, O., Beurskens, R., Behm, D. G., & Granacher, U. (2016). Effects of drop height and surface instability on neuromuscular activation during drop jumps. *Scandinavian Journal of Medicine & Science in Sports, 27*(10), 1090–1098. https://doi.org/10.1111/sms.12732

Liguori, G., Feito, Y., Fountaine, C., & Roy, B. A. (2021). *ACSM's guidelines for exercise testing and prescription: American College of Sports Medicine* (11th ed.). Lippincott williams and wilkins.

Miller, M. G., Berry, D. C., Gilders, R., & Bullard, S. (2007). Recommendations for implementing an aquatic plyometric program. *Strength and Conditioning Journal, 23*(6), 28–35. https://doi.org/10.1519/00126548- 200112000-00005

Mirzaei, B., Norasteh, A. A., & Asadi, A. (2013). Neuromuscular adaptations to plyometric training: depth jump vs. countermovement jump on Sand. *Sport Sciences for Health, 9*(3), 145–149. https://doi.org/10.1007/s11332-013-0161-x

Miyama, M., & Nosaka, K. (2004). Influence of surface on muscle damage and soreness induced by consecutive drop jumps. *Journal of Strength and Conditioning Research, 18*(2), 206–211. https://doi.org/10.1519/00124278-200405000-00002

Nagaraja, Y., & Gajanana Prabhu, B. (2017). Effect of eight weeks land and sand based plyometric training on selected physical and physiological variables. *International Journal of Physical Education, Fitness and Sports, 6*(2), 40–45. https://doi.org/10.26524/2017.06.02.9.

Ozen, G., Atar, O., & Koc, H. (2020). The effects of a 6-week plyometric training program on sand versus wooden parquet surfaces on the physical performance parameters of well-trained young basketball players. *Montenegrin Journal of Sports Science and Medicine, 9*(1), 27–32. https://doi.org/10.26773/mjssm.200304

Peitz, M., Behringer, M., & Granacher, U. (2018). A systematic review on the effects of resistance and plyometric training on physical fitness in youth - what do comparative studies tell us? *PloS One, 13*(10). https://doi.org/10.1371/journal.pone.0205525

Prieske, O., Muehlbauer, T., Mueller, S., Krueger, T., Kibele, A., Behm, D. G., & Granacher, U. (2013). Effects of surface instability on neuromuscular performance during drop jumps and landings. *European Journal of Applied Physiology, 113*(12), 2943–2951. https://doi.org/10.1007/s00421-013-2724-6

Ramírez-Campillo, R., Andrade, D. C., & Izquierdo, M. (2013). Effects of plyometric training volume and training surface on explosive strength. *Journal of Strength and Conditioning Research,* 27(10), 2714–2722. https://doi.org/10.1519/jsc.0b013e318280c9e9

Ramirez-Campillo, R., García-Pinillos, F., García-Ramos, A., Yanci, J., Gentil, P., Chaabene, H., & Granacher, U. (2018). Effects of different plyometric training frequencies on components of physical fitness in amateur female soccer players. *Frontiers in Physiology,* (9), 931. https://doi.org/10.3389/fphys.2018.00934

Resh, T., T, J., Meeran, R. B., & Kumar, V. P. R. S. (2017). Effect of plyometric exercise training on vertical jump height between ground and sand surface in male volleyball players. *International Journal of Pharma and Bio Sciences,* 8(3). https://doi.org/10.22376/ijpbs.2017.8.3.b370-376

Sozbir, K. (2016). Effects of 6-week plyometric training on vertical jump performance and muscle activation of lower extremity muscles. *The Sport Journal,* 3, 1-14.

APPENDICES FOR STUDY I

APPENDIX A

IRB APPROVAL LETTER

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129
FWA: 00005331/IRB Regn. 0003571

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Wednesday, May 12, 2021

Protocol Title	***Evaluation of Plyometric Training Surface and Training Volume on Power and Agility Performance Outcomes***
Protocol ID	**21-2173 4i**
Principal Investigator	**Cameron D. Addie** (Student)
Faculty Advisors	Jennifer Caputo & Richard Farley
Co-Investigators	NONE
Investigator Email(s)	*Cda5f@mtmail.mtsu.edu; jennifer.caputo@mtsu.edu; richard.farley@mtsu.edu*
Department	Health and Human Performance
Funding	**NONE**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU IRB through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 using the category *(4) Collection of data through noninvasive procedures* within the subcategories 4a & 4e. A summary of the IRB action is tabulated below:

IRB Action	**APPROVED for ONE YEAR**
Date of Expiration	**5/31/2022** *Date of Approval*: 5/12/21 *Recent Amendment*: NONE
Sample Size	THIRTY (30)
Participant Pool	*Target Population:* Primary Classification: **Healthy Adults (age range 18-35 years)** Specific Classification: **Physically active individuals**
Type of Interaction	☐ Non-interventional or Data Analysis ☐ Virtual/Remote/Online interaction ☒ **In person or physical interaction – Mandatory COVID-19 Management**
Exceptions	Contact infomration of the participants is allowed to coordinate this research and to enable a potential COVID-19 contact tracing
Restrictions	**1. Mandatory SIGNED Informed Consent.** **2. Other than the exceptions above, identifiable data/artifacts, such as, audio/video data, photographs, handwriting samples, personal address, driving records, social security number, and etc., MUST NOT be collected. Recorded identifiable information must be deidentified as described in the protocol.** **3. Mandatory Final report (refer last page).** **4. Mandatory participant exclusion criteria to screen out risky subjects.** **5. CDC guidelines and MTSU safe practice must be followed**
Approved Templates	*IRB Templates:* Signature Informed Consent and Recruitment Email *Non-MTSU Templates:* Verbal Recruitment Script
Research Inducement	NONE
Comments	NONE

Post-approval Requirements

The PI and FA must read and abide by the post-approval conditions (Refer "*Quick Links*" in the bottom):

- ***Reporting Adverse Events:*** The PI must report research-related adversities suffered by the participants, deviations from the protocol, misconduct, and etc., within 48 hours from when they were discovered.
- ***Final Report:*** The FA is responsible for submitting a final report to close-out this protocol before **5/31/2022** **(Refer to the Continuing Review section below)**; REMINDERS WILLNOT BE SENT. **Failure to close-out or request for a continuing review may result in penalties** including cancellation of the data collected using this protocol and/or withholding student diploma.
- ***Protocol Amendments***: An IRB approval must be obtained for all types of amendments, such as: addition/removal of subject population or investigating team; sample size increases; changes to the research sites (appropriate permission letter(s) may be needed); alternation to funding; and etc. The proposed amendments must be requested by the FA in an addendum request form. The proposed changes must be consistent with the approval category and they must comply with expedited review requirements
- ***Research Participant Compensation:*** Compensation for research participation must be awarded as proposed in Chapter 6 of the Expedited protocol. The documentation of the monetary compensation must Appendix J and MUST NOT include protocol details when reporting to the MTSU Business Office.
- ***COVID-19:*** Regardless whether this study poses a threat to the participants or not, refer to the COVID-19 Management section for important information for the FA.

Continuing Review (The PI has requested early termination)

Although this protocol can be continued for up to THREE years, The PI has opted to end the study by **5/31/2022** **The PI must close-out this protocol by submitting a final report before 5/31/2022 Failure to close-out may result in penalties that include cancellation of the data collected using this protocol and delays in graduation of the student PI.**

Post-approval Protocol Amendments:

The current MTSU IRB policies allow the investigators to implement minor and significant amendments that would fit within this approval category. ***Only TWO procedural amendments will be entertained per year*** *(changes like addition/removal of research personnel are not restricted by this rule).*

Date	Amendment(s)	IRB Comments
NONE	NONE.	NONE

Other Post-approval Actions:

The following actions are done subsequent to the approval of this protocol on request by the PI/FA or on recommendation by the IRB or by both.

Date	IRB Action(s)	IRB Comments
NONE	NONE	NONE

COVID-19 Management:

The PI must follow social distancing guidelines and other practices to avoid viral exposure to the participants and other workers when physical contact with the subjects is made during the study.

- The study must be stopped if a participant or an investigator should test positive for COVID-19 within 14 days of the research interaction. This must be reported to the IRB as an "adverse event."
- The MTSU's "Return-to-work" questionnaire found in Pipeline must be filled by the investigators on the day of the research interaction prior to physical contact.
- PPE must be worn if the participant would be within 6 feet from the each other or with an investigator.
- Physical surfaces that will come in contact with the participants must be sanitized between use
- **FA's Responsibility:** The FA is given the administrative authority to make emergency changes to protect the wellbeing of the participants and student researchers during the COVID-19 pandemic. However, the FA must notify the IRB after such changes have been made. The IRB will audit the changes at a later date and the FA will be instructed to carryout remedial measures if needed.

Data Management & Storage:

All research-related records (signed consent forms, investigator training and etc.) must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data must be stored for at least three (3) years after the study is closed. Additional Tennessee State data retention requirement may apply (*refer "Quick Links" for MTSU policy 129 below*). The data may be destroyed in a manner that maintains confidentiality and anonymity of the research subjects.

The MTSU IRB reserves the right to modify/update the approval criteria or change/cancel the terms listed in this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

- Post-approval Responsibilities: http://www.mtsu.edu/irb/FAQ/PostApprovalResponsibilities.php
- Expedited Procedures: https://mtsu.edu/irb/ExpeditedProcedures.php
- MTSU Policy 129: Records retention & Disposal: https://www.mtsu.edu/policies/general/129.php

APPENDIX B

CITI COURSEWORK REQUIREMENTS

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** CITI Health Information Privacy and Security (HIPS) Course
- **Course Learner Group:** HIPS
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 42319453
- **Completion Date:** 30-Apr-2021
- **Expiration Date:** 29-Apr-2025
- **Minimum Passing:** 80
- **Reported Score*:** 80

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Basics of Health Privacy (ID: 1417)	30-Apr-2021	5/5 (100%)
Health Privacy Issues for Students and Instructors (ID: 1420)	30-Apr-2021	5/5 (100%)
Basics of Information Security, Part 1 (ID: 1423)	30-Apr-2021	4/5 (80%)
Basics of Information Security, Part 2 (ID: 1424)	30-Apr-2021	5/5 (100%)
Picking and Protecting Passwords (ID: 1449)	30-Apr-2021	1/5 (20%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kc7183d29-743c-45f4-8ca5-8bda91f6ca15-42319453

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2

COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** CITI Health Information Privacy and Security (HIPS) Course
- **Course Learner Group:** HIPS
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 42319453
- **Report Date:** 04-May-2021
- **Current Score**:** 80

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Health Privacy Issues for Students and Instructors (ID: 1420)	30-Apr-2021	5/5 (100%)
Basics of Health Privacy (ID: 1417)	30-Apr-2021	5/5 (100%)
Basics of Information Security, Part 1 (ID: 1423)	30-Apr-2021	4/5 (80%)
Basics of Information Security, Part 2 (ID: 1424)	30-Apr-2021	5/5 (100%)
Picking and Protecting Passwords (ID: 1449)	30-Apr-2021	1/5 (20%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kc7183d29-743c-45f4-8ca5-8bda91f6ca15-42319453

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2

COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Institutional/Signatory Official: Human Subject Research
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916318
- **Completion Date:** 27-Apr-2021
- **Expiration Date:** 26-Apr-2024
- **Minimum Passing:** 80
- **Reported Score*:** 85

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Introduction to Being an Institutional Official (IO) (ID: 16640)	27-Apr-2021	5/5 (100%)
IO Knowledge Requirements: Human Subject Protections (ID: 16641)	27-Apr-2021	5/5 (100%)
Expectations of the IO (ID: 16642)	27-Apr-2021	5/5 (100%)
Challenges of Being an IO: Human Subject Protections (ID: 16643)	27-Apr-2021	2/5 (40%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kb050d0dc-b5eb-4a60-9452-f79eead33414-41916318

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Institutional/Signatory Official: Human Subject Research
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916318
- **Report Date:** 04-May-2021
- **Current Score**:** 85

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Introduction to Being an Institutional Official (IO) (ID: 16640)	27-Apr-2021	5/5 (100%)
IO Knowledge Requirements: Human Subject Protections (ID: 16641)	27-Apr-2021	5/5 (100%)
Expectations of the IO (ID: 16642)	27-Apr-2021	5/5 (100%)
Challenges of Being an IO: Human Subject Protections (ID: 16643)	27-Apr-2021	2/5 (40%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kb050d0dc-b5eb-4a60-9452-f79eead33414-41916318

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Human Research
- **Course Learner Group:** Social & Behavioral Research
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916316
- **Completion Date:** 27-Apr-2021
- **Expiration Date:** 26-Apr-2025
- **Minimum Passing:** 80
- **Reported Score*:** 100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Belmont Report and Its Principles (ID: 1127)	27-Apr-2021	3/3 (100%)
History and Ethical Principles - SBE (ID: 490)	27-Apr-2021	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	27-Apr-2021	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	27-Apr-2021	5/5 (100%)
Assessing Risk - SBE (ID: 503)	27-Apr-2021	5/5 (100%)
Informed Consent - SBE (ID: 504)	27-Apr-2021	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	27-Apr-2021	5/5 (100%)
Conflicts of Interest in Human Subjects Research (ID: 17464)	27-Apr-2021	5/5 (100%)
Middle Tennessee State University Module DEMO (ID: 1073)	27-Apr-2021	No Quiz

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kab3abdd4-7220-43d5-aab3-5b34ac47d26f-41916316

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2

COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Human Research
- **Course Learner Group:** Social & Behavioral Research
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916316
- **Report Date:** 04-May-2021
- **Current Score**:** 100

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Defining Research with Human Subjects - SBE (ID: 491)	27-Apr-2021	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	27-Apr-2021	5/5 (100%)
Belmont Report and Its Principles (ID: 1127)	27-Apr-2021	3/3 (100%)
Assessing Risk - SBE (ID: 503)	27-Apr-2021	5/5 (100%)
Informed Consent - SBE (ID: 504)	27-Apr-2021	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	27-Apr-2021	5/5 (100%)
History and Ethical Principles - SBE (ID: 490)	27-Apr-2021	5/5 (100%)
Middle Tennessee State University Module DEMO (ID: 1073)	27-Apr-2021	No Quiz
Conflicts of Interest in Human Subjects Research (ID: 17464)	27-Apr-2021	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kab3abdd4-7220-43d5-aab3-5b34ac47d26f-41916316

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

APPENDIX C

INFORMED CONSENT

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBF016: INFORMED CONSENT

(Use this consent template for in person or virtual interactions)

General Information

1. Use this consent form for requesting a participant for
   a. In person interviews or other interactions
   b. Virtual interviews or other interactions using Zoom
   c. Online consent via Qualtrics
2. This template is suitable for studies that qualify for Expedited as well as a full review.
3. Alterations and waiver of this template are strongly discouraged. The elements not applicable to the study can be indicated by the provided check boxes with a suitable justification.
4. Web-based Studies – this form is not currently available for web-based administration through Qualtrics.
5. The Faculty Advisor information will be removed at the review/approval stage if the PI is NOT a student.
6. COVID-19: for in person protocols, there is a COVID-19 avoidance plan in the informed consent section. An extra page for collecting participant information to enable contact tracing in the event the participant, or a person the participant came in contact with was found to be positive for COVID-19. This "extra page" is used only for contact tracing and will be destroyed after few days in accordance with CDC guidelines.

Instructions

1. This form contains TWO sections:
   A. General Information section – signed by the researcher and given to the participant
   B. The signature section has to be signed by the participant
   Please note that there are multiple options: first one for traditional pen signature, a second option is for virtual administration via Zoom, and a third option for Qualtrics
2. If signature waiver is approved or required by the IRB, then the signature section will be filled by the PI with a random identifier and saved with rest of the research records
3. Other than the actual signatures, the text boxes in two sections must be properly completed before submitting for IRB approval.
4. The investigators have the option for requesting the removal of certain elements in this form by entering their justification in the boxes highlighted in yellow. All of the pre-approval request boxes will be removed at the approval stage.

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBF016 – Participant Informed Consent

A. INFORMATION AND DISCLOSURE SEGMENT
(Participant Copy)

Study Title	Imapct of Plyometric Surface Composition and Training Volume on Lower Body Power and Agility Performacne		
Primary Investigator(s)	Cameron D. Addie	☒ **Student**	
Contact information	cda5f@mtmail.mtsu.edu		
Department & Institution	Health and Human Perfomance Sciences Behavorial and Health Sciences		
Faculty Advisors	Jennifer Caputo and Richard Flarley		
Protocol ID	**21-2173 4i**	**Approval: 05/12/2021**	**Expiration: 05/31/2022**

The following information is provided to inform you about the research project in which you have been invited to participate. Please read this disclosure and feel free to ask any questions. The investigators must answer all of your questions and you must be given a signed copy of this disclosure.

- Your participation in this research study is voluntary.
- You are also free to withdraw from this study at any time without loss of any benefits.
- In the event new information becomes available that may affect the risks or benefits associated with this research study, you will be notified so that you can make an informed decision at that time.

For additional information on your rights as a participant in this study, please contact the Middle Tennessee State University (MTSU) Office of Compliance (Tel 615-494-8918 or send your emails to irb_information@mtsu.edu. (URL: http://www.mtsu.edu/irb).

Please read this section and sign Section B if you wish to enroll in this study. The researcher will provide you with a copy of this disclosure form for you to keep for your future reference.

1. **What are the prime types of physical contact the participant will have?**
   The participant will have the following type(s) of contact(s) with the investigators or/and other participants at least sometimes during this research:
   ☐ 1.1 ***Virtual Interactions*** **NONE**

   ☒ 1.2 ***In person interactions***
   ☐ With PPE ☐ Without PPE ☒ With Social Distancing ☐ Without Social Distancing
   The participants will be asked to provide their contact details to be used by MTSU COVID-19 task force for contact tracing if needed

2. **What is the main category of this research?**
   ☐ 2.1 ***Educational Tests***
   ☐ 2.2 Social/***Behavioral Evaluation***
   ☐ 2.3 ***Psychological intervention or procedures***
   ☒ 2.4 ***Physical Evaluation or Procedures***
   ☐ 2.5 ***Medical Evaluation***
   ☐ *2.6 Clinical Research*

3. **What is the purpose of this study?**
   The purpose of this study is to investigate the effect of surface composition and training volume on plyometric training performance outcomes.

4. **What type of data will be collected from you?**
Your height and weight will be measured. Your maximum vertical and horizontal jumps will be measured using a force platform. Your agilty will be measured by recording how quickly you complete a pro-agaility test and the T-test.

5. **What are procedures we intend on doing to collect the above described data?**
On the first visit, you will complet paperwork and measurement of height and weight. The primary investigator will document your plyometric training history, current physical activity, and any injury history to assure you qualify for the study .After paper work, you will perform a 5-minute warm-up on a Monark exercise bike at your desired pace and resistance, and some jump rope. The principle investigator will demonstrate the assessments and allow you to practice. You will be required to perform the jumping and agility movements with correct mechanics to decrease risk of injury. To accomplish this, you will spend the first 2 weeks (3 trainign sessiosn) becoming familiar with the assessment and training movements.

After the familiarity phase (first 2 weeks), pre-testing will occur. All pre-testing assessments will be completed on the same day. You will perform a 5-minute warm-up on a Monark exercise bike at your desired pace and resistance, and some jump rope before pre-testing occurs.

You will complete the following assessments for the pre- and post-assessments:

1. Max countermovement jump: Bend you knees and then jump as high as you can while standing on a force platform. Trials will be conducted until height plateaus.
2. Squat jump: Stand on the force platform in a squatting position and then jump as high as you can. Trials will be conducted until height plateaus.
3. Broad jump: Stand on the force platform and then jump as far out as you can. Trials will be conducted until distance plateaus.
4. Pro agility: Starting in a 3-point stance you will sprint to a cone that is 5 meters away. You will then change direction and sprint 10 meters back to another cone. The last sprint is back to the starting position 5 meters away. Three trials will be conducted.T- test: On the start command, you will sprint forward 10 yards. You will shuffle sideways to a cone 5 yards to the right. Then shuflle 10 yards to the left to another cone. Lastly, you shuffle ba back to the center and run backwards to the start position. Three trials will be conducted .and the best time recorded.

Starting week 3, you will be randomized into one of 3 groups. The first group is a control group (plyometric training on gym floor), the second group is an experimental group (plyometric training on wrestling mat), and the third group is an experimental group (plyometric training on gym floor with increased volume). All groups will perform 2 training sessions every week with at least 48 hours of recovery between sessions. The plyometric training program will consit of varying training intensity drills for 6 weeks with sessions lasting 30-60 minutes. After the completion of the plyometric training program, post testing identical to the pre-test measures will be conducted.

The training program conducted on the gym floor and on the wresting mat are identical. They include a variety of jumping and agility drills: side to side hops, standing jumps and reaches, front cone hops, standing long jump, double leg hops, lateral jumps over barriers, double leg hops, diagonal cone hops, standing long jump with lateral sprint, single leg bounding, lateral jump single leg, cone hops with 180 degree turn, single leg bounding, a hexagon drill, cone hops with a change of direction sprint. Each session, will have bewteen 90-140 foot contacts (the number of times you land after a jump)

If you are in the high volume training program on gym floor, you will complete the same activities as those listed above. The only differnce is that sessions will have bewteen 110-200 foot contacts.

☐ 5.1 *Audio recording* ☐ 5.2 *Video Recording* ☐ 5.3 *Photography* ☒ 5.4 *NO audio/video recording*

6. **What will you be asked to do in this study?**
   You will be asked to perform plyometic excerises, vertical jumps, and agility assessments

7. **What are we planning to do with the data collected using your participation?**
   The data collected will be used for future publication.

8. **What are the expected results of this study and how will they be disseminated?**
   It is expected you will see an increase in lower body power performance and a decrease in agility time. The results of these studies will be used for future presentations and publications

9. **What is the approximate time commitment not including your preparation time for participating in this study?**
   This study involves an 8-week plyometric training program with sessions 2 days per week. Each session will last 30-60 minutes.

10. **What are your expected costs to you, your effort, and etc.?**
    There are no expected costs.

11. **What are the potential discomforts, inconveniences, and/or possible risks that can be reasonably expected as a result of participation in this study?**
    All physical activity poses a small risk of muscular injury. Additioanlly, you may feel muscle soreness after a training session. Muscle sorness will subside 24-48 hours after trianing a session.

12. **What are the risks and bodily harm due to COVID-19 exposure?**
    Although the MTSU IRB considers this research as "no more than minimal risk." the participants will be in physical contact with the PI and other participants during this study. Therefore, the participants will be exposed to the risk of contracting COVID-19.

    - ***The participants must adhere by the following to reduce the risk for infection.*** Participants must maintian a 6 foot distance from each other. All equipment will be cleaned after each training session
    - ***The investigator will follow these precautions:*** The investigator will make sure all participants maintain social distancing and all equipment is cleaned after each training session.
    - ***COVID-19 Contact Tracing:*** The participants will be asked to provide their contact details will be given to the MTSU COVID-19 task force if someone you came in contact with tested positive for COVID-19. Your contact details provided in this form will be destroyed after a few days if no positivity of COVID-19 is detected.

13. **What are the anticipated benefits from this study?**
    a. ***The benefits to science and humankind that may result from this research:*** Benfits from this study include helping Exercise Scientists understand if plyometric trainign outcomes can be improved by changing the surface of training or the volume of training.

b. ***The direct benefits to you which you may not receive outside the context of this research:*** You will receive free plyometric training for 8 weeks. You will learn about your agiltiy and lower body power. You wlll have increased leg strength and power following training.

14. **How will you be compensated for your participation?**
    There is no compensation for participating.

15. **Will you be compensated for any study-related injuries?**
    There will be no compensation if you are injured during the study.

16. **Circumstances under which the researcher may withdraw you from this study:**
    You will be withdrawn from the study if you miss two training sessions in the same week or if you miss more than two draining sessions.

17. **What happens if you choose to withdraw your participation?**
    There are no consequences from withdrawing from the study.

18. **Can you stop the participation any time after initially agreeing to give consent/assent?**
    You may stop participation anytime during the study.

19. **Contact Information.** If you should have any questions about this research study or possibly injury, please feel free to contact Cameron D. Addie by telephone 859-630-8588 or by email cda5f@mtmail.mtsu.edu OR my faculty advisor, Richard Farley or Jennifer Caputo , at 615-898-5298 or 615-898-5547. For additional information about giving consent of your rights as a participant in this study, to discuss problems, concerns and questions, or to offer input, please feel free to contact the MTSU IRB by email: compliance@mtsu.edu or by telephone (615) 494 8918.

20. **Confidentiality.** All efforts, within reason, will be made to keep your personal information private but total privacy cannot be promised. Your information may be shared with MTSU or the government, such as the Middle Tennessee State University Institutional Review Board, Federal Government Office for Human Research Protections, *if* you or someone else is in danger or if we are required to do so by law.

21. **Confidentiality and COVID-19:** Your information will be provided to the University COVID-19 task force or other public health officials in the event you or one of the research participants or investigators should test positive for COVID-19. Complete the COVID-19 Contract Tracking Page after you agree to consent.

You do not have to do anything if you decide not to participate. If you wish to enroll however, please enter your name and age in the attached Segment B document and sign in the space provided.

Consent obtained by:

Researcher's Signature Name and Title Date

<u>This study involves in person interactions. Therefore, the participant is required to complete the details in the next page to allow COVID-19 contact tracing if needed</u>

IRBF016 – Participant Informed Consent

B. Consent Segment 1 - IN PERSON INTERACTION

(Researchers' Copy)

Study Title	Imapct of Plyometric Surface Composition and Training Volume on Lower Body Power and Agility Performacne
Primary Investigator(s)	Cameron D. Addie ☒ **Student**
Contact information	cda5f@mtmail.mtsu.edu
Department & Institution	Health and Human Perfomance Sciences Behavorial and Health Sciences
Faculty Advisors	Jennifer Caputo and Richard Flarley
Protocol ID	**21-2173 4i** **Approval: 05/12/2021** **Expiration: 05/31/2022**

PARTICIPANT SECTION

To be filled by the participant and returned to the researcher	**Participants give consent**
I have read this informed consent document	☐No ☐Yes
The research procedures to be conducted have been explained to me verbally	☐No ☐Yes
I understand all of the interventions and all my questions have been answered	☐No ☐Yes
I am aware of the potential risks of the study	☐No ☐Yes
I agree to allow my information to be retained by the investigator for use in a potential COVID-19 contact tracing	☐No ☐Yes

By entering my name and signing below, I affirm that I freely and voluntarily choose to participate in this study. I understand I can withdraw from this study at any time without facing any consequences.

Name and Signature of the Participant Date Participant's Age

This study involves in person interactions. Therefore, the participant is required to complete the details in the next page to allow COVID-19 contact tracing if needed

RESEARCHER SECTION

(To be filled by an investigator and the FA if applicable)

Informed Consent obtained by: Faculty Verification (if administered by a student)

Name	Signature	Date	Name	Signature	Date

COVID-19 Contact Tracing

PARTICIPANT SECTION

(To be filled by the consenting participant and returned to the researcher)

Confidentiality and COVID-19:
Your information will be provided to the University COVID-19 task force or other public health officials in the event you or one of the research participants or investigators should test positive for COVID-19.

Name:
Contact Address:
Telephone:
Email Address:

Office Use:
Information Date: (Today's Date)
Expiration Date: (Date on which this sheet will be destroyed if no COVID-19 is detected)

Instruction to PI:

- Destroy this page if no COVID-19 is detected by the expiration date above
- If positivity for COVID-19 is known, then provide the participant contact information to MTSU's COVID-19 task force

Ensure to cut the box out when providing the participant's contact details and hide any protocol details from being transmitted.

APPENDIX D

PARTICIPANT SURVEY

Participant ID #______

Do you have any lower body injuries or other injuries that would keep you from performing a jump and sprint exercise routine? If yes, please provide information on when injury occurred.

What is your current exercise routine?

Have you done plyometric training before? If yes, please indicate when.

Training History-____________________

APPENDIX E

EMAIL RECRUITMENT LETTER

Hello!

My name is Cameron Addie and I am doctoral student at MTSU. I am collecting data for 2 separate research studies for my dissertation. I am currently looking for volunteers to participate in both studies. If you are interested in research, graduate school, or looking to add volunteer experience to your resume then this is a great opportunity to get involved! A description of both the studies can be found below. Please email me if you are interested in participating. My email is cda5f@mtmail.mtsu.edu

I am looking for participants who are:

1. Male or female
2. 18-35 years of age
3. No current or previous lower body injury in the past 6 months
4. Not currently performing a plyometric training program

Study 1: Plyometric training and surface composition on lower body power, and agility performance

This study involves an 8-week plyometric training program. Each session will last30-60 minutes.

- Your first visit will consist of completion of informed consent, and anthropometric data (height & weight). After paper work you will be performing a general warm-up (5-mintue Monark bike, 2 X 20 jump rope). Once the warm-up has been completed you will practice over all drills to get familiar with the testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).

- You will be then placed in one of two groups. The first group being plyometric on hard surface (wood floor), the second group will perform plyometric on soft surface (wrestling mat)

- You will practice these same testing drills for 3 more session before completing your pre-test data testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test). Once pre-test is completed you will then begin your 6 week plyometric training. Each session will roughly have 100-140 jumps (line jumps, cone hops, vertical jumps, broad jumps) following the 6 weeks of training you will then perform post testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).

- You can perform a maximum 2 session per week with at least 24 hours between each session.
- You will not allowed to be in the study if they cannot commit to the 8 total weeks of training. You are allowed to miss 2 session, but are not allowed to miss 2 session in the same week.

Study 2: Effect of volume on plyometric training on lower body power and agility performance
This study involves an 8 week plyometric training program. Each session should take about 30-60 minutes.

- Your first visit will consist of completion of informed consent, anthropometric data (height & weight). After paper work you will be performing a general warm-up (5-mintue Monark bike, 2 X 20 jump rope). Once the warm-up has been completed you will practice over all drills to get familiar with the testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).
- You will be placed in one of two groups. The first group being plyometric normal volume, the second group will perform plyometric with increased volume.
- You will then practice these same testing drills for 3 more session before completing your pre-test data testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test). Once pre-test is completed you will then begin your 6 week plyometric training. Each session will roughly have 100-140 jumps for group 1 and for group 2 to each session will roughly have 140-220 jumps. (line jumps, cone hops, vertical jumps, broad jumps) following the 6 weeks of training you will then be asked to perform post testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).
- You can perform a maximum 2 session per week with at least 24 hours between each session.

- You will not allowed to be in the study if they cannot commit to the 8 total weeks of training. You are allowed to miss 2 session, but are not allowed to miss 2 session in the same week.

Thank you and have a great day!

CHAPTER IV

THE EFFECTS OF PLYOMETRIC TRAINING VOLUME ON JUMP PERFORMANCE USING 6-WEEK PLYOMETRIC TRAINING PROGRAM

Introduction

A common method to increase horizontal and vertical power is plyometric training (PT). In PT, an eccentric pre-stretch followed by a shortened amortization phase within the stretch-shortening cycle (SSC) triggers the stretch reflex, enhancing the intensity of the subsequent concentric contraction. Volume is an important component to take into consideration when optimizing a PT program to improve power (Cadore et al., 2013; de Villarreal et al., 2008; de Villarreal et al., 2009). Training volume is commonly quantified as the number of foot contacts per session. The general prescription for optimal training adaptations suggests foot contacts of less than 80, 80-120, and more than 120 foot contacts per session for low, moderate, and high PT volume (Chu and Myer., 2013; de Villarreal et al., 2009). Chu and Myer (2013) further recommended 60-100, 100-150, and 150-250 foot contacts during the off season and 100-250, 150-300, and 150-450 during the preseason per session for beginner, intermediate, and advanced individuals, respectively. Other key factors to consider when prescribing PT volume include individual fitness level, training experience, specific goals, and the duration of the program. Sáez-Sáez de Villarreal et al (2010), suggested PT programs should span at least 10 weeks, with at least 20 sessions and at least 50 jumps of high intensity per session.

Several investigations have been conducted to compare low and moderate PT volume/frequency to high volume/frequency with physically active males and collegiate athletes (de Villarreal et al., 2008; Ebben et al., 2014; Jeffreys et al., 2019; Yanci et al., 2016). Overall, these studies revealed short-term (less than 7 weeks) PT using low to moderate frequency (1-2 days per week) and volume (180-460 foot contacts) produced similar enhancements in vertical and horizontal jump performance, reactive strength, and sprint performance versus high frequency (> 4 days per week) and volume (800-1200 foot contacts) training. The primary mechanism responsible for adaptations to PT programs of different volumes is unknown. However, it is plausible high volume results in overreaching or overtraining (de Villarreal et al., 2008) while lower volume reduces overuse injury due to reduced impact forces (Yanci et al., 2016). For example, while the benefit of post-activation potentiation can be observed acutely following PT, muscle performance is impaired 24-hours after PT (Cadore et al., 2013), with studies reporting muscle damage and soreness up to 3 days post-training compared to baseline (Chatzinikolaou et al., 2010). In accord, Ebben et al. (2014) suggested a minimum of 2 days between PT sessions, and an optimal range of 6 to 14 days post training to receive the physiological performance benefits.

With reduced time requirements and comparable development of vertical and horizontal power, there is evidence that PT programs with lower volume demonstrate similar training efficiency compared to PT with high volume. However, there is a lack of research variety on PT volume and the effect on jump performance using PAI. Establishing an appropriate volume for PT is important in designing safe, effective, and personalized training programs. This optimization not only enhances performance outcomes but also contributes to a more comprehensive understanding of the impact of PT volume on overall performance. It is important to comprehend how alternative training volumes may be employed to optimize specific adaptations that can be applicable to a wide range of populations. Therefore, the aim of this study was to compare the impact of PT volume during a 6-week PT program on changes in vertical and horizontal lower body power assessed by; squat jump (SJ), countermovement jump (CMJ), approach jump (AJ), and broad jump (BJ) performance in PAI. It was hypothesized that increasing PT volume would increase SJ, CMJ, AJ, and BJ compared to moderate PT volume group.

Methods

Study Design

The experimental study was approved by the local Institutional Review Board (IRB Approval #: 21-2173 4i; see Appendix A). The dependent variables were SJ, CMJ, AJ, and BJ. The independent variable was training volume (moderate versus high volume). G*Power (version 3.1.9.4) was used to calculate a priori sample size for the within-between interaction of a 2x2 repeated measures ANOVA. The recommended sample size was 6 participants per group to have power of .80, assuming a medium effect size and correlation of .85 among the repeated measures. The training duration was 6 weeks.

Participants

All volunteers were recruited from the university and signed an informed consent prior to participation. To be included, participants needed to be physically active based off the American College of Sports Medicine pre-participation screening algorithm (participating in physical activity at least 3 days a week for the past 3 months; Liguori et al., 2021), free from lower limb musculoskeletal injuries (within the past 6 months), and not actively participating in any PT program. The 12 males who participated were randomly assigned to moderate volume (*n* = 6; age: 24.0 ± 6.0 year; body mass 77.7 ± 17.0 kg; height 1.7 ± 0.1 m) and high volume (*n* = 6; age: 21.3 ± 2.5 year; body mass 78.5 ± 8.1 kg; height 1.8 ± 0.1 m) training groups based on their order of recruitment. Odd number participants (1, 3, 5, 7, 9, 11) were assigned to the moderate volume while even number participants (2, 4, 6, 8, 10, 12) were assigned to the high volume group.

Materials and Procedures

Participants read and signed the informed consent and completed the PT, muscular skeletal injury, and physical activity history forms (see Appendix B) to determine if they met the inclusion criteria. Participants were instructed to wear athletic attire for all sessions. Wearing shoes, body mass was measured using a digital scale (Tanita, Arlington Heights, IL, USA) and height was measured with shoes on using a stadiometer (SECA 222, Chino, CA, USA). Before the pre-testing phase, participants engaged in a warm-up comprising 10 repetitions each of jump rope, air squats, ankle hops, and countermovement jumps at a self-selected intensity. A 1-minute rest interval separated each exercise during all training and testing sessions. Subsequent to the warm-up, participants had a rest period, during which instructions were provided on how to execute each jump (SJ, CMJ, AJ and BJ).

For the SJ, participants were instructed to set their feet hip width apart, squat into a semi-squatted position, and hold that position (3-5 seconds) with the arm pulled back to the side. On a cue from the primary investigator, participants were instructed to maximally engage their leg muscles and explode upward with arms raised above the head without any countermovement. For the CMJ, participants were instructed to set up in the same initial manner as the SJ jump, then quickly squat down to a self-selected depth while pulling the arms back, and rapidly ascending into the air while throwing the arms upward overhead. For the AJ, participants were instructed to take a 3-step approach (left, right, left or right, left, right) to act as a breaking mechanism to convert the horizontal momentum into vertical propulsion, participants used the same approach for their AJ for each testing and training session. Lastly for the BJ participants were instructed to perform the jump using a bilateral stance for both take-off and landing, while swinging their arms and bending their knees to provide maximal horizontal propulsion forward. Participants were also instructed to have a knee bend of 90 to 110 degrees (Ducharme et al., 2016; Wakai & Linthorne, 2005).

Before the formal testing, participants executed three submaximal SJ, CMJ, AJ, and BJ with an arm swing. The assessments for each testing session were conducted in the same order: BJ, SJ, CMJ, and AJ. Participants rested for 30 seconds between jump attempts and 2 minutes when switching to a new jump assessments. The data analysis utilized the best trial, and all testing trials occurred on a hardwood surface. Vertical assessments (SJ, CMJ, AJ) were measured using a Vertec™ Vertical Jump Trainer (Sports Imports, Worthington, OH, USA). The distance of the BJ was measured in centimeters from the heel upon landing, using a tape measure. (Martin Sports, Carlstadt, NJ, USA). Both groups performed testing and training regimen on a solid wood gymnasium floor. Participants underwent a 2-week accommodation period to familiarize themselves with the training program. Within this timeframe, they completed the initial two weeks of the training, allowing them to adapt to the program's requirements and receive guidance on proper form and technique. Following the accommodation period the pre-test was administered. Following the pre-test the 6-week training program commenced. After completing the full 6-week program, participants took a post-test 24-72 hours after their last training session. The post-test procedures mirrored those of the pre-test.

Training Protocol

Throughout the study, participants committed to maintaining their existing exercise routines. Both volume groups engaged in an identical set of plyometric exercises aimed at enhancing lower body power (refer to Table 1). The only distinction is the high PT volume group completed 30% more volume per training session. The PT program utilized in this study was developed by Miller et al. (2007) and Sozbir et al. (2016). All participants attended two supervised training sessions per week, with a minimum 48-hour gap between sessions, totaling 12 training sessions. Participants were allowed to miss up to two training sessions. Each session commenced with a warm-up consisting of standing long jumps, ankle hops covering a 25-meter distance, and 10 countermovement jumps (CMJs). During each training session, a 30-second break separated each set, and a 1-minute break occurred between each exercise. The total duration of each session ranged from 20 to 40 minutes. No participants dropped out or sustained injuries during the entirety of the PT study.

Statistical Analysis

The mean differences for BJ, SJ, CMJ, and AJ were compared using four 2 (Volume: moderate and high) x 2 (Time: pre-test and post-test) repeated measures ANOVAs. An alpha level of $p \leq .05$ was used to determine statistical differences. Effect sizes were reported as partial eta squared (η_p^2) and Cohen's d (calculated as $(Mean_2 - Mean_1) / SD_{pooled}$) for the ANOVAs and mean differences, respectively. All statistical analyses were completed using IBM SPSS V. 29 (Armonk, NY, USA).

Results

Broad Jump

The results of the repeated measures ANOVA for BJ indicated no significant 2-way interaction ($F_{1,10} = 0.09$, $p = .767$, $\eta_p^2 = .01$). There was, however, significant main effects for time ($F_{1,10} = 22.12$, $p = .001$, $\eta_p^2 = .69$, $d = 0.73$) and volume ($F_{1,10} = 4.98$, $p = .050$, $\eta_p^2 = .33$, $d = 1.29$; see Table 2).

Squat Jump

The results of repeated measures ANOVA for SJ indicated no significant 2-way interaction ($F_{1,10} = 2.92$, $p = .118$, $\eta_p^2 = .23$). In addition, there were no significant main effects for time ($F_{1,10} = 3.46$, $p = .093$, $\eta_p^2 = .26$) or volume ($F_{1,10} = 0.04$, $p = .844$, $\eta_p^2 = .004$; see Table 2).

Counter-Movement Jump

The results of the repeated measures ANOVA for CMJ indicated no significant 2-way interaction ($F_{1,10}$ = 2.02, p = .186, η_p^2 = .17) and no significant main effect for volume ($F_{1,10}$ = 0.34, p = .573, η_p^2 = .03). There was a significant main effect for time ($F_{1,10}$ = 7.62, p = .020, η_p^2 = .43, d = 0.18 see Table 2).

Approach Jump

The repeated measures ANOVA for AJ indicated no significant 2-way interaction ($F_{1,10}$ = 0.08, p = .783, η_p^2 = .01) and no significant main effect for volume ($F_{1,10}$ = 0.53, p = .482, η_p^2 = .05). There was a significant main effect for time ($F_{1,10}$ = 54.64, p < .001, η_p^2 = .85, d = 0.53 see Table 2).

Table 1

6-Week Plyometric Training Program Protocol

Week	Volume (Foot Contacts)		Plyometric Exercises	Sets x Reps	
	Moderate	High		Moderate	High
1	90	115	Lateral ankle hops*	2 x 15	3 X 15
			Counter-movement jump*	2 x 15	3 X 15
			Front barrier jumps*	5 x 6	5 X 5
2	120	150	Lateral ankle hops*	2 x 15	3 X 15
			Standing long jump*	5 x 6	5 X 6
			Lateral barrier jumps**	2 x 15	3 X 15
			Tuck jumps**	5 x 6	5 X 6
3	120	150	Lateral ankle hops*	2 x 12	3 X 10
			Standing long jump*	4 x 6	3 X 10
			Lateral barrier jumps**	2 x 12	3 X 10
			Tuck jumps**	3 x 8	3 X 10
			Lateral barrier jumps**	2 x 12	3 X 10
4	140	180	Diagonal barrier jumps*	4 x 8	4 X 10
			Standing long jump with lateral sprint**	4 x 8	4 X 10
				2 x 12	2 X 12
			Lateral barrier jumps**	4 x 7	5 X 7
			Single leg bound***	4 x 6	6 X 6

			Side to side unilateral jumps***		
5	140	180	Diagonal barrier jumps*	2 x 7	4 X 7
			Standing long jump with lateral sprint**	4 x 7	4 X 8
			Lateral barrier jumps**	4 x 7	4 X 7
			Barrier jumps with half turn**	4 x 7	4 X 8
			Single leg bound***	4 x 7	4 X 8
			Side to side unilateral jumps***	2 x 7	4 X 7
6	120	150	Diagonal barrier jumps*	2 x 12	3 X 10
			Hexagon drill*	2 x 12	2 X 12
			Barrier jumps with directional sprints**	4 x 6	5 X 6
			Tuck jumps**	3 x 8	5 X 8
			Side to side unilateral jumps***	4 x 6	5 X 6

***Note.* * = low intensity; ** = medium intensity; *** = high intensity.**

Table 2. *Descriptive statistics for performance outcomes based on training volume (cm).*

Variable	Moderate Volume		High Volume		All Volumes	
	Mean	SD	Mean	SD	Mean	SD
Broad jump*						
Pre	226.2	13.8	245.2	16.0	235.7	14.9
Post	239.5	9.7	256.9	14.0	248.2*	12.8
Post-Pre	13.3		11.7			
All Times	232.8	11.8	251.0	15.0		
Squat jump						
Pre	55.7	10.0	59.0	5.1	57.3	7.6
Post	60.2	11.2	59.2	8.6	59.7	9.9
Post-Pre	4.6		0.2			
All Times						
Counter-movement jump*						
Pre	61.9	9.5	65.9	7.1	63.9	8.3
Post	64.4	9.5	66.7	7.9	65.5*	8.7
Post-pre	2.5		0.8			
All Times						
Approach jump*						
Pre	66.0	10.5	70.1	6.7	68.1	8.6
Post	71.1	9.7	74.9	7.2	73.0*	8.5
Post-Pre	5.1		4.8			
All Times						

Note. *Post-test jump height significantly greater (p < .05) than pre-test jump height.

Discussion

The purpose of this study was to compare the impact of volume on changes in vertical and horizontal lower body power measured by SJ, CMJ, AJ, and BJ performance following a 6-week PT program. The moderate group completed a total of 1460 contacts and the high group completed 1850 foot contacts. The results indicated similar improvements from pre- to post-test in BJ, SJ, CMJ, and AJ for the moderate and high volume groups. However, it is notable that the high volume group exhibited significantly better performance for this outcome at both pre- and post-test. Finally, neither group exhibited improvements in SJ from pre-test to post-test.

Like previous research on moderate and high volume PT with athlete and non-athlete populations, the current sample exhibited comparable enhancements in BJ, CMJ, and AJ following both volume protocols (de Villarreal et al., 2009; Jeffreys et al., 2019; Yanci et al., 2016). Continuing assessments of moderate to high PT volume using a non-athletic population expands the applicability of PT beyond sports performance. The current study findings demonstrate significant increases in BJ, CMJ, and AJ following a 6-week PT program using either a moderate or high volume (see table 2). Further, the mean differences signify practically significant increases in each of these outcomes.. On average, the study participants experienced an increase in BJ ranging from 11.7 to 13.3 cm, CMJ from .8 to 2.5 cm, and AJ from 4.8 to 5.1 cm, highlighting the effectiveness of the PT program.

Although similar improvements were observed between groups following PT, the high volume group started with significantly better BJ performance. It is not known if these programs would have been equally effective if the participants demonstrated similar baselines. Lastly, methodological differences may explain why the current findings differ from those reported by Ramírez-Campillo et al. (2013), who observed larger improvements in fast SSC actions (drop jumps and sprints) following high volume PT (120 foot contacts per session; 1460 total foot contacts) compared with moderate volume PT (60 foot contacts per session; 780 total foot contacts). After the first week of the PT program, both volume conditions in the current study either matched or surpassed the high volume condition reported by Ramírez-Campillo et al. (2013), likely explaining why groups in the current study demonstrated significant improvement in CMJ and AJ performance.

Although the results of the current study indicate comparable improvements in measures of horizontal and vertical jumping performance, there was no increase in SJ performance for either group. These findings contradict those of previous investigations (de Villarreal et al., 2009; Jeffreys et al., 2019; Potach & Chu., 2008; Ramírez-Campillo et al., 2013; Yanci et al., 2016). Because the current study utilized participants with low PT history, changes in all training outcomes would be expected. There is not a definitive explanation for the lack of SJ improvement for the participants of the current study. However, potential reasons include a lack of specificity in the PT program that targeted the movement patterns associated with the SJ and technical issues involving poor technique and form during the SJ. Another possible explanation is the program may not have been ideally designed for the participants based on their prior lack of PT experience. For example, Ramírez-Campillo et al. (2013) found that only those in the moderate volume

PT group (60 foot contacts per session; 780 total foot contacts) improved SJ performance, while their high volume group (120 foot contacts per session; 1460 total foot contacts) did not exhibit meaningful changes. Again, because the volume of the moderate group in the current study was equivalent to that of the high volume group for Ramírez-Campillo et al. (2013), the training volume was potentially too high, particularly for this sample. Finally, although there were no statistically significant changes in SJ performance from pre- to post-test observed, it is notable that the mean difference for the moderate group was 4.6 cm and only 0.2 cm for the high volume group. Additionally, performance at pre-test for the high volume group was comparable to that at post-test of the moderate volume group. Further research is warranted to understand the influence of PT volume on SJ performance in this population.

The practicality of this study only applies to PAI with minimal PT history. In alignment with the principle of specificity, it is notable that the emphasis of a given PT program is likely to yield improvements in complementary types of jumping (deVillareal et al., 2009; Yanci et al., 2019). Future research should continue to examine the influence of program volume while considering the vertical or horizontal components of the program, specifically assessing how those transfer to vertical and horizontal jump performance. It remains unclear how a lower training volume would influence horizontal and vertical jump performance with this population. Additionally, while performance outcomes were assessed, the lack of biomechanical data and reactive strength index limits our ability to provide insight into the mechanisms driving SSC enhancement. Future studies can be strengthened by including these variables.

In conclusion, the results of the present study indicate that implementing moderate volume (90-140 foot contacts per training session; 1460 total foot contacts) to high volume (115-180 foot contacts per training session; 1850 total foot. contacts) PT for 6 weeks improves horizontal (BJ) and vertical (CMJ and AJ) lower body power for PAI. However, no changes in SJ performance were observed post-training for either group. Interestingly, our results indicate higher PT volume (as measure by jumps) does not lead to greater improvements in jumping performance for PAI, leading to question the need for higher training volumes. With this knowledge, practitioners should individualize training volume based on factors such as training status, history, and injury status to optimize outcomes and minimize injury risk.

Chapter IV References

Chatzinikolaou, A., Fatouros, I. G., Gourgoulis, V., Avloniti, A., Jamurtas, A. Z., Nikolaidis, M. G., Douroudos, I., Michailidis, Y., Beneka, A., Malliou, P., Tofas, T., Georgiadis, I., Mandalidis, D., & Taxildaris, K. (2010). Time course of changes in performance and inflammatory responses after acute plyometric exercise. *Journal of Strength and Conditioning Research*, *24*(5), 1389–1398. https://doi.org/10.1519/jsc.0b013e3181d1d318

Chu, D. (1998). Jumping into plyometrics. Human Kinetics.

Chu, D. A., & Myer, G. D. (2013). Plyometrics. Human Kinetics.

Cadore, E. L., Pinheiro, E., Izquierdo, M., Correa, C. S., Radaelli, R., Martins, J. B., Lhullier, F. L. R., Laitano, O., Cardoso, M., & Pinto, R. S. (2013). Neuromuscular, hormonal, and metabolic responses to different plyometric training volumes in rugby players. *Journal of Strength and Conditioning Research*, *27*(11), 3001–3010. https://doi.org/10.1519/jsc.0b013e31828c32de

de Villarreal, E. S. S., González-Badillo, J. J., & Izquierdo, M. (2008). Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. Journal of Strength and Conditioning Research, 22(3), 715–725. https://doi.org/10.1519/jsc.0b013e318163eade

de Villarreal, E. S.-S., Kellis, E., Kraemer, W. J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: a meta-analysis. Journal of Strength and Conditioning Research, 23(2), 495–506. https://doi.org/10.1519/jsc.0b013e318196b7c6

Ebben, W. P., Suchomel, T. J., & Garceau, L. R. (2014, October). The effect of plyometric training volume on jumping performance. In ISBS-Conference Proceedings Archive.

Horita, T., Komi, P. V., Nicol, C., & Kyrolainen, H. (1999). Effect of exhausting stretch-shortening cycle exercise on the time course of mechanical behavior in the drop jump: Possible role of muscle damage. *European Journal of Applied Physiology, 79*(2), 160–167. https://doi.org/10.1007/s004210050490

Jeffreys, M. A., De Ste Croix, M. B. A., Lloyd, R. S., Oliver, J. L., & Hughes, J. D. (2019). The effect of varying plyometric volume on stretch-shortening cycle capability in collegiate male rugby players. *Journal of Strength and Conditioning Research, 33(*1), 139–145. https://doi.org/10.1519/jsc.0000000000001907

Miller, M. G., Berry, D. C., Gilders, R., & Bullard, S. (2001). Recommendations for implementing an aquatic plyometric program. *Strength and Conditioning Journal, 23*(6), 28–35. https://doi.org/10.1519/00126548-200112000-00005

Ramírez-Campillo, R., Henríquez-Olguín, C., Burgos, C., Andrade, D. C., Zapata, D., Martínez, C., Álvarez, C., Baez, E. I., Castro-Sepúlveda, M., Peñailillo, L., & Izquierdo, M. (2015). Effect of progressive volume-based overload during plyometric training on explosive and endurance performance in young soccer players. *Journal of Strength and Conditioning Research*, *29*(7), 1884–1893. https://doi.org/10.1519/jsc.0000000000000836

Sozbir, K. (2016). Effects of 6-week plyometric training on vertical jump performance and muscle activation of lower extremity muscles. *The Sport Journal, 3,* 1-14.

Sáez-Sáez de Villarreal, E., Requena, B., & Newton, R. U. (2010). Does plyometric training improve strength performance? A meta-analysis. *Journal of Science and Medicine in Sport*, *13*(5), 513–522. https://doi.org/10.1016/j.jsams.2009.08.005

Watkins, C. M., Gill, N. D., Maunder, E., Downes, P., Young, J. D., McGuigan, M. R., & Storey, A. G. (2020). The effect of low-volume preseason plyometric training on Force-velocity profiles in semiprofessional rugby union players. *Journal of Strength and Conditioning Research*, *35*(3), 604–615. https://doi.org/10.1519/jsc.0000000000003917

Yanci, J., Castillo, D., Iturricastillo, A., Ayarra, R., & Nakamura, F. Y. (2017). Effects of two different volume-equated weekly distributed short-term plyometric training programs on futsal players physical performance. *Journal of Strength and Conditioning Research, 31*(7), 1787–1794. https://doi.org/10.1519/jsc.0000000000001644

Yanci, J., Los Arcos, A., Camara, J., Castillo, D., García, A., & Castagna, C. (2016). Effects of horizontal plyometric training volume on soccer players' performance. *Research in Sports Medicine*, *24*(4), 308–319. https://doi.org/10.1080/15438627.2016.1222280

APPENDICES FOR STUDY II

APPENDIX A

IRB APPROVAL LETTER

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129
FWA: 00005331/IRB Regn. 0003571

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN001 - EXPEDITED PROTOCOL APPROVAL NOTICE

Wednesday, May 12, 2021

Protocol Title	***Evaluation of Plyometric Training Surface and Training Volume on Power and Agility Performance Outcomes***
Protocol ID	**21-2173 4i**
Principal Investigator	**Cameron D. Addie** (Student)
Faculty Advisors	Jennifer Caputo & Richard Farley
Co-Investigators	NONE
Investigator Email(s)	*Cda5f@mtmail.mtsu.edu; jennifer.caputo@mtsu.edu; richard.farley@mtsu.edu*
Department	Health and Human Performance
Funding	**NONE**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU IRB through the **EXPEDITED** mechanism under 45 CFR 46.110 and 21 CFR 56.110 using the category *(4) Collection of data through noninvasive procedures* within the subcategories 4a & 4e. A summary of the IRB action is tabulated below:

IRB Action	**APPROVED for ONE YEAR**		
Date of Expiration	**5/31/2022**	*Date of Approval:* 5/12/21	*Recent Amendment:* NONE
Sample Size	THIRTY (30)		
Participant Pool	*Target Population:* Primary Classification: **Healthy Adults (age range 18-35 years)** Specific Classification: **Physically active individuals**		
Type of Interaction	☐ Non-interventional or Data Analysis ☐ Virtual/Remote/Online interaction ☒ **In person or physical interaction – Mandatory COVID-19 Management**		
Exceptions	Contact infomration of the participants is allowed to coordinate this research and to enable a potential COVID-19 contact tracing		
Restrictions	**1. Mandatory SIGNED Informed Consent.** **2. Other than the exceptions above, identifiable data/artifacts, such as, audio/video data, photographs, handwriting samples, personal address, driving records, social security number, and etc., MUST NOT be collected. Recorded identifiable information must be deidentified as described in the protocol.** **3. Mandatory Final report (refer last page).** **4. Mandatory participant exclusion criteria to screen out risky subjects.** **5. CDC guidelines and MTSU safe practice must be followed**		
Approved Templates	*IRB Templates:* Signature Informed Consent and Recruitment Email *Non-MTSU Templates:* Verbal Recruitment Script		
Research Inducement	NONE		
Comments	NONE		

Post-approval Requirements

The PI and FA must read and abide by the post-approval conditions (Refer "*Quick Links*" in the bottom):

- ***Reporting Adverse Events:*** The PI must report research-related adversities suffered by the participants, deviations from the protocol, misconduct, and etc., within 48 hours from when they were discovered.
- ***Final Report:*** The FA is responsible for submitting a final report to close-out this protocol before **5/31/2022** **(Refer to the Continuing Review section below)**; REMINDERS WILLNOT BE SENT. **Failure to close-out or request for a continuing review may result in penalties** including cancellation of the data collected using this protocol and/or withholding student diploma.
- ***Protocol Amendments***: An IRB approval must be obtained for all types of amendments, such as: addition/removal of subject population or investigating team; sample size increases; changes to the research sites (appropriate permission letter(s) may be needed); alternation to funding; and etc. The proposed amendments must be requested by the FA in an addendum request form. The proposed changes must be consistent with the approval category and they must comply with expedited review requirements
- ***Research Participant Compensation:*** Compensation for research participation must be awarded as proposed in Chapter 6 of the Expedited protocol. The documentation of the monetary compensation must Appendix J and MUST NOT include protocol details when reporting to the MTSU Business Office.
- ***COVID-19:*** Regardless whether this study poses a threat to the participants or not, refer to the COVID-19 Management section for important information for the FA.

Continuing Review (The PI has requested early termination)

Although this protocol can be continued for up to THREE years, The PI has opted to end the study by **5/31/2022** **The PI must close-out this protocol by submitting a final report before 5/31/2022 Failure to close-out may result in penalties that include cancellation of the data collected using this protocol and delays in graduation of the student PI.**

Post-approval Protocol Amendments:

The current MTSU IRB policies allow the investigators to implement minor and significant amendments that would fit within this approval category. ***Only TWO procedural amendments will be entertained per year*** *(changes like addition/removal of research personnel are not restricted by this rule).*

Date	Amendment(s)	IRB Comments
NONE	NONE.	NONE

Other Post-approval Actions:

The following actions are done subsequent to the approval of this protocol on request by the PI/FA or on recommendation by the IRB or by both.

Date	IRB Action(s)	IRB Comments
NONE	NONE	NONE

COVID-19 Management:

The PI must follow social distancing guidelines and other practices to avoid viral exposure to the participants and other workers when physical contact with the subjects is made during the study.

- The study must be stopped if a participant or an investigator should test positive for COVID-19 within 14 days of the research interaction. This must be reported to the IRB as an "adverse event."
- The MTSU's "Return-to-work" questionnaire found in Pipeline must be filled by the investigators on the day of the research interaction prior to physical contact.
- PPE must be worn if the participant would be within 6 feet from the each other or with an investigator.
- Physical surfaces that will come in contact with the participants must be sanitized between use
- **FA's Responsibility:** The FA is given the administrative authority to make emergency changes to protect the wellbeing of the participants and student researchers during the COVID-19 pandemic. However, the FA must notify the IRB after such changes have been made. The IRB will audit the changes at a later date and the FA will be instructed to carryout remedial measures if needed.

Data Management & Storage:

All research-related records (signed consent forms, investigator training and etc.) must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data must be stored for at least three (3) years after the study is closed. Additional Tennessee State data retention requirement may apply (*refer "Quick Links" for MTSU policy 129 below*). The data may be destroyed in a manner that maintains confidentiality and anonymity of the research subjects.

The MTSU IRB reserves the right to modify/update the approval criteria or change/cancel the terms listed in this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

- Post-approval Responsibilities: http://www.mtsu.edu/irb/FAQ/PostApprovalResponsibilities.php
- Expedited Procedures: https://mtsu.edu/irb/ExpeditedProcedures.php
- MTSU Policy 129: Records retention & Disposal: https://www.mtsu.edu/policies/general/129.php

APPENDIX B

CITI COURSEWORK REQUIREMENTS

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2

COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** CITI Health Information Privacy and Security (HIPS) Course
- **Course Learner Group:** HIPS
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 42319453
- **Completion Date:** 30-Apr-2021
- **Expiration Date:** 29-Apr-2025
- **Minimum Passing:** 80
- **Reported Score*:** 80

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Basics of Health Privacy (ID: 1417)	30-Apr-2021	5/5 (100%)
Health Privacy Issues for Students and Instructors (ID: 1420)	30-Apr-2021	5/5 (100%)
Basics of Information Security, Part 1 (ID: 1423)	30-Apr-2021	4/5 (80%)
Basics of Information Security, Part 2 (ID: 1424)	30-Apr-2021	5/5 (100%)
Picking and Protecting Passwords (ID: 1449)	30-Apr-2021	1/5 (20%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kc7183d29-743c-45f4-8ca5-8bda91f6ca15-42319453

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** CITI Health Information Privacy and Security (HIPS) Course
- **Course Learner Group:** HIPS
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 42319453
- **Report Date:** 04-May-2021
- **Current Score**:** 80

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Health Privacy Issues for Students and Instructors (ID: 1420)	30-Apr-2021	5/5 (100%)
Basics of Health Privacy (ID: 1417)	30-Apr-2021	5/5 (100%)
Basics of Information Security, Part 1 (ID: 1423)	30-Apr-2021	4/5 (80%)
Basics of Information Security, Part 2 (ID: 1424)	30-Apr-2021	5/5 (100%)
Picking and Protecting Passwords (ID: 1449)	30-Apr-2021	1/5 (20%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kc7183d29-743c-45f4-8ca5-8bda91f6ca15-42319453

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2

COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Institutional/Signatory Official: Human Subject Research
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916318
- **Completion Date:** 27-Apr-2021
- **Expiration Date:** 26-Apr-2024
- **Minimum Passing:** 80
- **Reported Score*:** 85

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Introduction to Being an Institutional Official (IO) (ID: 16640)	27-Apr-2021	5/5 (100%)
IO Knowledge Requirements: Human Subject Protections (ID: 16641)	27-Apr-2021	5/5 (100%)
Expectations of the IO (ID: 16642)	27-Apr-2021	5/5 (100%)
Challenges of Being an IO: Human Subject Protections (ID: 16643)	27-Apr-2021	2/5 (40%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kb050d0dc-b5eb-4a60-9452-f79eead33414-41916318

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)
COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Institutional/Signatory Official: Human Subject Research
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916318
- **Report Date:** 04-May-2021
- **Current Score**:** 85

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Introduction to Being an Institutional Official (IO) (ID: 16640)	27-Apr-2021	5/5 (100%)
IO Knowledge Requirements: Human Subject Protections (ID: 16641)	27-Apr-2021	5/5 (100%)
Expectations of the IO (ID: 16642)	27-Apr-2021	5/5 (100%)
Challenges of Being an IO: Human Subject Protections (ID: 16643)	27-Apr-2021	2/5 (40%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kb050d0dc-b5eb-4a60-9452-f79eead33414-41916318

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2

COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Human Research
- **Course Learner Group:** Social & Behavioral Research
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916316
- **Completion Date:** 27-Apr-2021
- **Expiration Date:** 26-Apr-2025
- **Minimum Passing:** 80
- **Reported Score*:** 100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Belmont Report and Its Principles (ID: 1127)	27-Apr-2021	3/3 (100%)
History and Ethical Principles - SBE (ID: 490)	27-Apr-2021	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	27-Apr-2021	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	27-Apr-2021	5/5 (100%)
Assessing Risk - SBE (ID: 503)	27-Apr-2021	5/5 (100%)
Informed Consent - SBE (ID: 504)	27-Apr-2021	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	27-Apr-2021	5/5 (100%)
Conflicts of Interest in Human Subjects Research (ID: 17464)	27-Apr-2021	5/5 (100%)
Middle Tennessee State University Module DEMO (ID: 1073)	27-Apr-2021	No Quiz

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kab3abdd4-7220-43d5-aab3-5b34ac47d26f-41916316

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2

COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Cameron Addie (ID: 10035971)
- **Institution Affiliation:** Middle Tennessee State University (ID: 714)
- **Institution Email:** cda5f@mtmail.mtsu.edu
- **Phone:** 859-630-8588

- **Curriculum Group:** Human Research
- **Course Learner Group:** Social & Behavioral Research
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 41916316
- **Report Date:** 04-May-2021
- **Current Score**:** 100

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Defining Research with Human Subjects - SBE (ID: 491)	27-Apr-2021	5/5 (100%)
The Federal Regulations - SBE (ID: 502)	27-Apr-2021	5/5 (100%)
Belmont Report and Its Principles (ID: 1127)	27-Apr-2021	3/3 (100%)
Assessing Risk - SBE (ID: 503)	27-Apr-2021	5/5 (100%)
Informed Consent - SBE (ID: 504)	27-Apr-2021	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	27-Apr-2021	5/5 (100%)
History and Ethical Principles - SBE (ID: 490)	27-Apr-2021	5/5 (100%)
Middle Tennessee State University Module DEMO (ID: 1073)	27-Apr-2021	No Quiz
Conflicts of Interest in Human Subjects Research (ID: 17464)	27-Apr-2021	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kab3abdd4-7220-43d5-aab3-5b34ac47d26f-41916316

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

APPENDIX C

INFORMED CONSENT

IRB

INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBF016: INFORMED CONSENT

(Use this consent template for in person or virtual interactions)

General Information

1. Use this consent form for requesting a participant for
   a. In person interviews or other interactions
   b. Virtual interviews or other interactions using Zoom
   c. Online consent via Qualtrics
2. This template is suitable for studies that qualify for Expedited as well as a full review.
3. Alterations and waiver of this template are strongly discouraged. The elements not applicable to the study can be indicated by the provided check boxes with a suitable justification.
4. Web-based Studies – this form is not currently available for web-based administration through Qualtrics.
5. The Faculty Advisor information will be removed at the review/approval stage if the PI is NOT a student.
6. COVID-19: for in person protocols, there is a COVID-19 avoidance plan in the informed consent section. An extra page for collecting participant information to enable contact tracing in the event the participant, or a person the participant came in contact with was found to be positive for COVID-19. This "extra page" is used only for contact tracing and will be destroyed after few days in accordance with CDC guidelines.

Instructions

1. This form contains TWO sections:
   A. General Information section – signed by the researcher and given to the participant
   B. The signature section has to be signed by the participant
   Please note that there are multiple options: first one for traditional pen signature, a second option is for virtual administration via Zoom, and a third option for Qualtrics
2. If signature waiver is approved or required by the IRB, then the signature section will be filled by the PI with a random identifier and saved with rest of the research records
3. Other than the actual signatures, the text boxes in two sections must be properly completed before submitting for IRB approval.
4. The investigators have the option for requesting the removal of certain elements in this form by entering their justification in the boxes highlighted in yellow. All of the pre-approval request boxes will be removed at the approval stage.

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBF016 – Participant Informed Consent
A. INFORMATION AND DISCLOSURE SEGMENT
(Participant Copy)

Study Title	Imapct of Plyometric Surface Composition and Training Volume on Lower Body Power and Agility Performacne		
Primary Investigator(s)	Cameron D. Addie	☒ **Student**	
Contact information	cda5f@mtmail.mtsu.edu		
Department & Institution	Health and Human Perfomance Sciences Behavorial and Health Sciences		
Faculty Advisors	Jennifer Caputo and Richard Flarley		
Protocol ID	**21-2173 4i**	**Approval: 05/12/2021**	**Expiration: 05/31/2022**

The following information is provided to inform you about the research project in which you have been invited to participate. Please read this disclosure and feel free to ask any questions. The investigators must answer all of your questions and you must be given a signed copy of this disclosure.

- Your participation in this research study is voluntary.
- You are also free to withdraw from this study at any time without loss of any benefits.
- In the event new information becomes available that may affect the risks or benefits associated with this research study, you will be notified so that you can make an informed decision at that time.

For additional information on your rights as a participant in this study, please contact the Middle Tennessee State University (MTSU) Office of Compliance (Tel 615-494-8918 or send your emails to irb_information@mtsu.edu. (URL: http://www.mtsu.edu/irb).

Please read this section and sign Section B if you wish to enroll in this study. The researcher will provide you with a copy of this disclosure form for you to keep for your future reference.

1. **What are the prime types of physical contact the participant will have?**
   The participant will have the following type(s) of contact(s) with the investigators or/and other participants at least sometimes during this research:
   ☐ 1.1 *Virtual Interactions* **NONE**
   ☒ 1.2 *In person interactions*
   ☐ With PPE ☐ Without PPE ☒ With Social Distancing ☐ Without Social Distancing
   The participants will be asked to provide their contact details to be used by MTSU COVID-19 task force for contact tracing if needed

2. **What is the main category of this research?**
   ☐ 2.1 *Educational Tests*
   ☐ 2.2 Social/*Behavioral Evaluation*
   ☐ 2.3 *Psychological intervention or procedures*
   ☒ 2.4 *Physical Evaluation or Procedures*
   ☐ 2.5 *Medical Evaluation*
   ☐ 2.6 *Clinical Research*

3. **What is the purpose of this study?**
   The purpose of this study is to investigate the effect of surface composition and training volume on plyometric training performance outcomes.

4. **What type of data will be collected from you?**
   Your height and weight will be measured. Your maximum vertical and horizontal jumps will be measured using a force platform. Your agilty will be measured by recording how quickly you complete a pro-agaility test and the T-test.

5. **What are procedures we intend on doing to collect the above described data?**
   On the first visit, you will complet paperwork and measurement of height and weight. The primary investigator will document your plyometric training history, current physical activity, and any injury history to assure you qualify for the study .After paper work, you will perform a 5-minute warm-up on a Monark exercise bike at your desired pace and resistance, and some jump rope. The principle investigator will demonstrate the assessments and allow you to practice. You will be required to perform the jumping and agility movements with correct mechanics to decrease risk of injury. To accomplish this, you will spend the first 2 weeks (3 trainign sessiosn) becoming familiar with the assessment and training movements.

   After the familiarity phase (first 2 weeks), pre-testing will occur. All pre-testing assessments will be completed on the same day. You will perform a 5-minute warm-up on a Monark exercise bike at your desired pace and resistance, and some jump rope before pre-testing occurs.

   You will complete the following assessments for the pre- and post-assessments:

   1. Max countermovement jump: Bend you knees and then jump as high as you can while standing on a force platform. Trials will be conducted until height plateaus.
   2. Squat jump: Stand on the force platform in a squatting position and then jump as high as you can. Trials will be conducted until height plateaus.
   3. Broad jump: Stand on the force platform and then jump as far out as you can. Trials will be conducted until distance plateaus.
   4. Pro agility: Starting in a 3-point stance you will sprint to a cone that is 5 meters away. You will then change direction and sprint 10 meters back to another cone. The last sprint is back to the starting position 5 meters away. Three trials will be conducted.T- test: On the start command, you will sprint forward 10 yards. You will shuffle sideways to a cone 5 yards to the right. Then shuflle 10 yards to the left to another cone. Lastly, you shuffle ba back to the center and run backwards to the start position. Three trials will be conducted .and the best time recorded.

   Starting week 3, you will be randomized into one of 3 groups. The first group is a control group (plyometric training on gym floor), the second group is an experimental group (plyometric training on wrestling mat), and the third group is an experimental group (plyometric training on gym floor with increased volume). All groups will perform 2 training sessions every week with at least 48 hours of recovery between sessions. The plyometric training program will consit of varying training intensity drills for 6 weeks with sessions lasting 30-60 minutes. After the completion of the plyometric training program, post testing identical to the pre-test measures will be conducted.

   The training program conducted on the gym floor and on the wresting mat are identical. They include a variety of jumping and agility drills: side to side hops, standing jumps and reaches, front cone hops, standing long jump, double leg hops, lateral jumps over barriers, double leg hops, diagonal cone hops, standing long jump with lateral sprint, single leg bounding, lateral jump single leg, cone hops with 180 degree turn, single leg bounding, a hexagon drill, cone hops with a change of direction sprint. Each session, will have bewteen 90-140 foot contacts (the number of times you land after a jump)

If you are in the high volume training program on gym floor, you will complete the same activities as those listed above. The only differnce is that sessions will have bewteen 110-200 foot contacts.

☐ 5.1 *Audio recording* ☐ 5.2 *Video Recording* ☐ 5.3 *Photography* ☒ 5.4 *NO audio/video recording*

6. **What will you be asked to do in this study?**
   You will be asked to perform plyometic excerises, vertical jumps, and agility assessments

7. **What are we planning to do with the data collected using your participation?**
   The data collected will be used for future publication.

8. **What are the expected results of this study and how will they be disseminated?**
   It is expected you will see an increase in lower body power performance and a decrease in agility time. The results of these studies will be used for future presentations and publications

9. **What is the approximate time commitment not including your preparation time for participating in this study?**
   This study involves an 8-week plyometric training program with sessions 2 days per week. Each session will last 30-60 minutes.

10. **What are your expected costs to you, your effort, and etc.?**
    There are no expected costs.

11. **What are the potential discomforts, inconveniences, and/or possible risks that can be reasonably expected as a result of participation in this study?**
    All physical activity poses a small risk of muscular injury. Additioanlly, you may feel muscle soreness after a training session. Muscle sorness will subside 24-48 hours after trianing a session.

12. **What are the risks and bodily harm due to COVID-19 exposure?**
    Although the MTSU IRB considers this research as "no more than minimal risk." the participants will be in physical contact with the PI and other participants during this study. Therefore, the participants will be exposed to the risk of contracting COVID-19.

    - ***The participants must adhere by the following to reduce the risk for infection.*** Participants must maintian a 6 foot distance from each other. All equipment will be cleaned after each training session
    - ***The investigator will follow these precautions:*** The investigator will make sure all participants maintain social distancing and all equipment is cleaned after each training session.
    - ***COVID-19 Contact Tracing:*** The participants will be asked to provide their contact details will be given to the MTSU COVID-19 task force if someone you came in contact with tested positive for COVID-19. Your contact details provided in this form will be destroyed after a few days if no positivity of COVID-19 is detected.

13. **What are the anticipated benefits from this study?**
    a. ***The benefits to science and humankind that may result from this research:*** Benfits from this study include helping Exercise Scientists understand if plyometric trainign outcomes can be improved by changing the surface of training or the volume of training.

b. ***The direct benefits to you which you may not receive outside the context of this research:*** You will receive free plyometric training for 8 weeks. You will learn about your agiltiy and lower body power. You wlll have increased leg strength and power following training.

14. **How will you be compensated for your participation?**
    There is no compensation for participating.

15. **Will you be compensated for any study-related injuries?**
    There will be no compensation if you are injured during the study.

16. **Circumstances under which the researcher may withdraw you from this study:**
    You will be withdrawn from the study if you miss two training sessions in the same week or if you miss more than two draining sessions.

17. **What happens if you choose to withdraw your participation?**
    There are no consequences from withdrawing from the study.

18. **Can you stop the participation any time after initially agreeing to give consent/assent?**
    You may stop participation anytime during the study.

19. **Contact Information.** If you should have any questions about this research study or possibly injury, please feel free to contact Cameron D. Addie by telephone 859-630-8588 or by email cda5f@mtmail.mtsu.edu OR my faculty advisor, Richard Farley or Jennifer Caputo , at 615-898-5298 or 615-898-5547. For additional information about giving consent of your rights as a participant in this study, to discuss problems, concerns and questions, or to offer input, please feel free to contact the MTSU IRB by email: compliance@mtsu.edu or by telephone (615) 494 8918.

20. **Confidentiality.** All efforts, within reason, will be made to keep your personal information private but total privacy cannot be promised. Your information may be shared with MTSU or the government, such as the Middle Tennessee State University Institutional Review Board, Federal Government Office for Human Research Protections, *if* you or someone else is in danger or if we are required to do so by law.

21. **Confidentiality and COVID-19:** Your information will be provided to the University COVID-19 task force or other public health officials in the event you or one of the research participants or investigators should test positive for COVID-19. Complete the COVID-19 Contract Tracking Page after you agree to consent.

You do not have to do anything if you decide not to participate. If you wish to enroll however, please enter your name and age in the attached Segment B document and sign in the space provided.

Consent obtained by:

Researcher's Signature Name and Title Date

This study involves in person interactions. Therefore, the participant is required to complete the details in the next page to allow COVID-19 contact tracing if needed

IRBF016 – Participant Informed Consent

B. Consent Segment 1 - IN PERSON INTERACTION
(Researchers' Copy)

Study Title	Imapct of Plyometric Surface Composition and Training Volume on Lower Body Power and Agility Performacne
Primary Investigator(s)	Cameron D. Addie ☒ **Student**
Contact information	cda5f@mtmail.mtsu.edu
Department & Institution	Health and Human Perfomance Sciences Behavorial and Health Sciences
Faculty Advisors	Jennifer Caputo and Richard Flarley
Protocol ID	**21-2173 4i** **Approval: 05/12/2021** **Expiration: 05/31/2022**

PARTICIPANT SECTION

To be filled by the participant and returned to the researcher	**Participants give consent**
I have read this informed consent document	☐No ☐Yes
The research procedures to be conducted have been explained to me verbally	☐No ☐Yes
I understand all of the interventions and all my questions have been answered	☐No ☐Yes
I am aware of the potential risks of the study	☐No ☐Yes
I agree to allow my information to be retained by the investigator for use in a potential COVID-19 contact tracing	☐No ☐Yes

By entering my name and signing below, I affirm that I freely and voluntarily choose to participate in this study. I understand I can withdraw from this study at any time without facing any consequences.

Name and Signature of the Participant | Date | Participant's Age

This study involves in person interactions. Therefore, the participant is required to complete the details in the next page to allow COVID-19 contact tracing if needed

RESEARCHER SECTION

(To be filled by an investigator and the FA if applicable)

Informed Consent obtained by: | Faculty Verification (if administered by a student)

Name | Signature | Date | Name | Signature | Date

COVID-19 Contact Tracing

PARTICIPANT SECTION

(To be filled by the consenting participant and returned to the researcher)

Confidentiality and COVID-19:
Your information will be provided to the University COVID-19 task force or other public health officials in the event you or one of the research participants or investigators should test positive for COVID-19.

Name:
Contact Address:
Telephone:
Email Address:

Office Use:
Information Date: (Today's Date)
Expiration Date: (Date on which this sheet will be destroyed if no COVID-19 is detected)

Instruction to PI:
- Destroy this page if no COVID-19 is detected by the expiration date above
- If positivity for COVID-19 is known, then provide the participant contact information to MTSU's COVID-19 task force

Ensure to cut the box out when providing the participant's contact details and hide any protocol details from being transmitted.

APPENDIX D

PARTICIPANT SURVEY

Participant ID #______

Do you have any lower body injuries or other injuries that would keep you from performing a jump and sprint exercise routine? If yes, please provide information on when injury occurred.

What is your current exercise routine?

Have you done plyometric training before? If yes, please indicate when.

Training History-____________________

APPENDIX E

EMAIL RECRUITMENT LETTER

Hello!

My name is Cameron Addie and I am doctoral student at MTSU. I am collecting data for 2 separate research studies for my dissertation. I am currently looking for volunteers to participate in both studies. If you are interested in research, graduate school, or looking to add volunteer experience to your resume then this is a great opportunity to get involved! A description of both the studies can be found below. Please email me if you are interested in participating. My email is cda5f@mtmail.mtsu.edu

I am looking for participants who are:

5. Male or female
6. 18-35 years of age
7. No current or previous lower body injury in the past 6 months
8. Not currently performing a plyometric training program

Study 1: Plyometric training and surface composition on lower body power, and agility performance

This study involves an 8-week plyometric training program. Each session will last30-60 minutes.

- Your first visit will consist of completion of informed consent, and anthropometric data (height & weight). After paper work you will be performing a general warm-up (5-mintue Monark bike, 2 X 20 jump rope). Once the warm-up has been completed you will practice over all drills to get familiar with the testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).
- You will be then placed in one of two groups. The first group being plyometric on hard surface (wood floor), the second group will perform plyometric on soft surface (wrestling mat)
- You will practice these same testing drills for 3 more session before completing your pre-test data testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test). Once pre-test is completed you will then begin your 6 week plyometric training. Each session will roughly have 100-140 jumps (line jumps, cone hops, vertical jumps, broad jumps) following the 6 weeks of training

you will then perform post testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).

- You can perform a maximum 2 session per week with at least 24 hours between each session.
- You will not allowed to be in the study if they cannot commit to the 8 total weeks of training. You are allowed to miss 2 session, but are not allowed to miss 2 session in the same week.

Study 2: Effect of volume on plyometric training on lower body power and agility performance

This study involves an 8 week plyometric training program. Each session should take about 30-60 minutes.

- Your first visit will consist of completion of informed consent, anthropometric data (height & weight). After paper work you will be performing a general warm-up (5-mintue Monark bike, 2 X 20 jump rope). Once the warm-up has been completed you will practice over all drills to get familiar with the testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).
- You will be placed in one of two groups. The first group being plyometric normal volume, the second group will perform plyometric with increased volume.
- You will then practice these same testing drills for 3 more session before completing your pre-test data testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test). Once pre-test is completed you will then begin your 6 week plyometric training. Each session will roughly have 100-140 jumps for group 1 and for group 2 to each session will roughly have 140-220 jumps. (line jumps, cone hops, vertical jumps, broad jumps) following the 6 weeks of training you will then be asked to perform post testing (countermovement jumps, squat jump, broad jump and pro agility test, and t-test).
- You can perform a maximum 2 session per week with at least 24 hours between each session.

- You will not allowed to be in the study if they cannot commit to the 8 total weeks of training. You are allowed to miss 2 session, but are not allowed to miss 2 session in the same week.

Thank you and have a great day!

CHAPTER V

OVERALL CONCLUSIONS

There were two purposes of this dissertation. The first purpose was to compare the effects of a 6-week PT program on a hard or soft surface on changes in vertical lower body power, and the second purpose was compare the impact of PT volume during a 6-week PT program on changes in vertical and horizontal lower body power. The study was approved by University Institutional Review Board and participants signed an informed consent before completing the training program. College-age students who were free from lower body injury in the past 6 months and were not currently performing a PT program participated in the study.

In the first study, the effects of training surface following a 6-week PT program on vertical jump performance was assessed by SJ, CMJ, and AJ. The initial session included reading and signing the informed consent and completing the surveys to assure they met the inclusion criteria. The plyometric survey questions included PT history, overall training history, current physical activity, and injury history. Additionally, age, height, and body mass were measured and recorded. Participants were randomly assigned to the soft and hard surface training group with participant sex used to counterbalance group placement. The hard surface training group performed their training regimen on a solid wood gymnasium floor, while the soft surface training group trained on a 2-inch-thick wrestling mat placed on top of the gymnasium floor.

Participants wore athletic attire for all testing and training sessions. Following the initial session, Participants performed a 2-week accommodation period to become familiarized with the training program. During this period, participants completed the first two weeks of the training program, allowing them to acclimate to the training requirements and receive instructions on proper form and technique. Participants performed a pre-test after the 2-week accommodation period where max SJ, CMJ, and AJ were measured using a Vertec™. Following the pre-test, participants performed the 6-week PT program on their assigned surface. Participants completed two training sessions per week, and were allowed to miss two training sessions, as long as not occurring in the same week. Following the PT program the participants performed their post-test in the same manner as their pre-test.

The results indicated significant increases in vertical jump performance for all outcome measures (SJ, CMJ, and AJ) on both surfaces. Potential sources of these adaptations include improvements in neuromuscular adaptations, SSC enhancement, muscular strength, and power development irrespective of training surface (Aagaard, 2003; Behrens et al., 2013; Hedayatpour & Falla, 2015). When designing a PT program, practitioners and coaches can prioritize individual goals and consider personal preferences for and access to various training surfaces. Future research should continue to examine underlying neuromuscular adaptations and biomechanical analysis of PT performed on different surfaces and how that may affect vertical power development.

In the second study, the effects of PT volume on vertical and horizontal jump performance, assessed by BJ, SJ, CMJ, and AJ were studied. Session one was the same for studies 1 and 2, with assessment of study inclusion criteria and completion of informed consent documents by those who qualified for participation Participants were randomized into the moderate or high volume training groups based on their order of recruitment. Odd number participants (1, 3, 5, 7, 9, 11) were assigned to the moderate volume group while even number participants (2, 4, 6, 8, 10, 12) were assigned to the high volume group.

Both training groups performed their PT on a hard training surface. The moderate volume group performed between 90-140 foot contacts per training session for a total of 1460 foot contacts during the study while the high volume group performed between 115-180 foot contacts per training session for a total of1850 foot contacts. Participants wore athletic attire for all testing and training sessions. Following the initial session, Participants performed a 2-week accommodation period to become familiarized with the training program. During this period, participants completed the first two weeks of the training program, allowing them to acclimate to the training requirements and receive instructions on proper form and technique. Participants performed a pre-test after the 2-week accommodation period, where vertical jump was assessed by SJ, CMJ, and AJ using a Vertec™. Horizontal jump distance was assessed with BJ and was measured from the heel upon landing using a tape measure. Following the pre-test, participants performed the 6-week PT program. Participants underwent the identical training protocol as in study 1. Subsequently, after completing the PT program, participants conducted the post-test in the same manner as the pre-test the same PT.

Following the varied volume PT, there was no statistically significant increase in SJ performance. However, there were increases in CMJ, AJ, and BJ performance following the PT program for both training volumes. Interestingly, our results indicate that higher PT volume (as measure by foot contacts) did not lead to greater improvements in jumping performance for PAI. Therefore, increasing PT volume is not required to elicit greater improvements in vertical and horizontal jumping performance. With this understanding, practitioners and coaches should tailor PT volume to individual's needs, while considering factors like training background, injury history, and current training status to maximize benefits while reducing the risk of injury.

Overall conclusions

In these samples of PAI there were statistically significant increases in vertical and horizontal jump performance in all training surface and training volume groups. These results indicate that training surface may not be a limiting factor in enhancing jumping performance and that the PT program itself may play an important role. In addition, the results indicate that PT volume between 1460 and 1850 foot contacts is sufficient to increase both vertical and horizontal jump performance. Future research should include defining the minimum volume threshold that can elicit benefits in jump performance for PAI. Additionally, there is a shortage of kinematic and kinetic data on the changes that occur from PT with PAI. The lack of these research data limit the capacity to identify potential mechanisms driving SSC enhancement. Ultimately, PAI who engage in PT may choose the training surface and volume of their choice based on individual goals, preferences, and training readiness, as well as considering access to facilities and equipment. Lastly, the adage “more is better” was not supported by these data in designing PT programs for PAI.

REFERENCES

Aagaard, P. (2003). Training-induced changes in neural function. *Exercise and Sport Sciences Reviews*, *31*(2), 61–67. https://doi.org/10.1097/00003677-200304000-00002

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Neural adaptation to resistance training: changes in evoked V-wave and H-reflex responses. *Journal of Applied Physiology*, *92*(6), 2309–2318. https://doi.org/10.1152/japplphysiol.01185.2001

Ahmadi, M., Nobari, H., Ramirez-Campillo, R., Pérez-Gómez, J., Ribeiro, A. L., & Martínez-Rodríguez, A. (2021). Effects of plyometric jump training in sand or rigid surface on jump-related biomechanical variables and physical fitness in female volleyball players. *International Journal of Environmental Research and Public Health*, *18*(24), 13093. https://doi.org/10.3390/ijerph182413093

Arabatzi, F., Kellis, E., & Saèz-Saez De Villarreal, E. (2010). Vertical jump biomechanics after plyometric, weight lifting, and combined (weight Lifting + plyometric) training. *Journal of Strength and Conditioning Research*, *24*(9), 2440–2448. https://doi.org/10.1519/jsc.0b013e3181e274ab

Arazi, H., & Asadi, A. (2011). The effect of aquatic and land plyometric training on strength, Sprint, and balance in young basketball players. *Journal of Human Sport and Exercise*, *6*(1), 101–111. https://doi.org/10.4100/jhse.2011.61.12

Arazi, H., Mohammadi, M., & Asadi, A. (2014). Muscular adaptations to depth jump plyometric training: Comparison of sand vs. land surface. *Interventional Medicine and Applied Science*, *6*(3), 125–130. https://doi.org/10.1556/imas.6.2014.3.5

Asadi, A. (2014). Use of rating of perceived exertion for determining plyometric exercises intensity in physically active men. *Sport Sciences for Health*, *10*(2), 75–78. https://doi.org/10.1007/s11332-014-0176-y

Asadi, A., Arazi, H., Young, W. B., & de Villarreal, E. S. (2016). The effects of plyometric training on change-of-direction ability: A meta-analysis. *International Journal of Sports Physiology and Performance*, *11*(5), 563–573. https://doi.org/10.1123/ijspp.2015-0694

Baker, D. (2003). Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *The Journal of Strength and Conditioning Research*, *17*(3), 493. https://doi.org/10.1519/1533-4287(2003)017<0493:aeoaha>2.0.co;2

Ball, N. B., & Scurr, J. C. (2009). Bilateral neuromuscular and force differences during a plyometric task. *Journal of Strength and Conditioning Research*, 23(5), 1433–1441. https://doi.org/10.1519/jsc.0b013e3181a4e97f

Behm, D. G. (1995). Neuromuscular implications and applications of resistance training. *Journal of Strength and Conditioning Research*, *9*(4), 264–274. https://doi.org/10.1519/00124278-199511000-00014

Behrens, M., Mau-Moeller, A., & Bruhn, S. (2013a). Effect of plyometric training on neural and mechanical properties of the knee extensor muscles. *International Journal of Sports Medicine*, *35*(02), 101–119. https://doi.org/10.1055/s-0033-1343401

Borg, G. A. V. (1982a). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5). https://doi.org/10.1249/00005768-198205000-00012

Bouguezzi, R., Chaabene, H., Negra, Y., Ramirez-Campillo, R., Jlalia, Z., Mkaouer, B., & Hachana, Y. (2020). Effects of different plyometric training frequencies on measures of athletic performance in prepuberal male soccer players. *Journal of Strength and Conditioning Research*, *34*(6), 1609–1617. https://doi.org/10.1519/jsc.0000000000002486

Brown, A. C., Wells, T. J., Schade, M. L., Smith, D. L., & Fehling, P. C. (2007). Effects of plyometric training versus traditional weight training on strength, power, and aesthetic jumping ability in female collegiate dancers. *Journal of Dance Medicine & Science*, *11*(2), 38–44.

Buğa, S., & Gencer, Y. G. (2022). The effect of plyometric training performed on different surfaces on some performance parameters. *Journal of Progress in Nutrition*, *24*, 1-9. https://doi.org/10.23751/pn.v24iS1.13014

Cadore, E. L., Pinheiro, E., Izquierdo, M., Correa, C. S., Radaelli, R., Martins, J. B., Lhullier, F. L., Laitano, O., Cardoso, M., & Pinto, R. S. (2013). Neuromuscular, hormonal, and metabolic responses to different plyometric training volumes in rugby players. *Journal of Strength and Conditioning Research*, *27*(11), 3001–3010. https://doi.org/10.1519/jsc.0b013e31828c32de

Carlson, K., Magnusen, M., & Walters, P. (2009). Effect of various training modalities on vertical jump. *Research in Sports Medicine*, *17*(2), 84–94. https://doi.org/10.1080/15438620902900351

Carter, A. B., Kaminski, T. W., Douex Jr, A. T., Knight, C. A., & Richards, J. G. (2007). Effects of high-volume upper extremity plyometric training on throwing velocity and functional strength ratios of the shoulder rotators in collegiate baseball players. *Journal of Strength and Conditioning Research*, *21*(1), 208–215. https://doi.org/10.1519/00124278-200702000-00038

Carvalho, A., Mourão, P., & Abade, E. (2014). Effects of strength training combined with specific plyometric exercises on body composition, vertical jump height and lower limb strength development in elite male handball players: A case study. *Journal of Human Kinetics*, *41*(1), 125–132. https://doi.org/10.2478/hukin-2014-0040

Çđmenlđ, Ö., Koç, H., Çđmenlđ, F., & Kaçoğlu, C. (2016). Effect of an eight-week plyometric training on different surfaces on the jumping performance of male volleyball players. *Journal of Physical Education and Sport*, *16*(1), 162–163. https://doi.org/10.7752/jpes.2016.01026

Chelly, M. S., Ghenem, M. A., Abid, K., Hermassi, S., Tabka, Z., & Shephard, R. J. (2010). Effects of in-season short-term plyometric training program on leg power, jump- and sprint performance of soccer players. *Journal of Strength and Conditioning Research*, *24*(10), 2670–2676. https://doi.org/10.1519/jsc.0b013e3181e2728f

Cherni, Y., Hammami, M., Jelid, M. C., Aloui, G., Suzuki, K., Shephard, R. J., & Chelly, M. S. (2021). Neuromuscular adaptations and enhancement of physical performance in female basketball players after 8 weeks of plyometric training. *Frontiers in Physiology*, *11*. https://doi.org/10.3389/fphys.2020.588787

Chimera, N. J., Swanik, K. A., Swanik, B. C., & Straub, S. J. (2004). Effects of plyometric training on muscle-activation strategies and performance in female athletes. *Journal of Athletic Training*, *39*(1), 24–31. https://doi.org/PMC385258

Chu, D. A. (1998). *Jumping into plyometrics*. Human Kinetics Champaign, IL.

Chu, Donald A., & Plummer, L. (1984). Jumping into plyometrics: The language of plyometrics. *National Strength & Conditioning Association Journal*, *6*(5), 30. https://doi.org/10.1519/0744-0049(1984)006<0030:tlop>2.3.co;2

Clarkson, P. M., & Tremblay, I. (1988). Exercise-induced muscle damage, repair, and adaptation in humans. *Journal of Applied Physiology*, *65*(1), 1–6. https://doi.org/10.1152/jappl.1988.65.1.1

Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Power absorption and production during slow, large-amplitude stretch-shorten cycle motions. *European Journal of Applied Physiology*, *87*(1), 59–65. https://doi.org/10.1007/s00421-002-0585-5

Davies, G., Riemann, B. L., & Manske, R. (2015). Current concepts of plyometric exercise. *International journal of sports physical therapy*, *10*(6), 760–786.

de Marche Baldon, R., Moreira Lobato, D. F., Yoshimatsu, A. P., dos Santos, A. F., Francisco, A. L., Pereira Santiago, P. R., & Serrão, F. V. (2014). Effect of plyometric training on lower limb biomechanics in females. *Clinical Journal of Sport Medicine*, *24*(1), 44–50. https://doi.org/10.1097/01.jsm.0000432852.00391.de

de Villarreal, E. S., González-Badillo, J. J., & Izquierdo, M. (2008). Low and moderate plyometric training frequency produces greater jumping and sprinting gains compared with high frequency. *Journal of Strength and Conditioning Research*, *22*(3), 715–725. https://doi.org/10.1519/jsc.0b013e318163eade

de Villarreal, E. S.-S., Kellis, E., Kraemer, W. J., & Izquierdo, M. (2009). Determining variables of plyometric training for improving vertical jump height performance: A meta-analysis. *Journal of Strength and Conditioning Research*, *23*(2), 495–506. https://doi.org/10.1519/jsc.0b013e318196b7c6

Di Giminiani, R., & Petricola, S. (2016). The power output-drop height relationship to determine the optimal dropping intensity and to monitor the training intervention. *Journal of Strength and Conditioning Research*, *30*(1), 117–125. https://doi.org/10.1519/jsc.0000000000001076

Donoghue, O. A., Shimojo, H., & Takagi, H. (2011). Impact forces of plyometric exercises performed on land and in water. *Sports Health: A Multidisciplinary Approach*, *3*(3), 303–309. https://doi.org/10.1177/1941738111403872

Dotan, R., Mitchell, C., Cohen, R., Klentrou, P., Gabriel, D., & Falk, B. (2012). Child—adult differences in Muscle activation — A review. *Pediatric Exercise Science*, *24*(1), 2–21. https://doi.org/10.1123/pes.24.1.2

Earle, R., & Baechle, T. R. (2004). The NSCA's Essentials of personal training text. *Strength and Conditioning Journal*, *26*(2), 76. https://doi.org/10.1519/1533-4295(2004)026<0076:tneopt>2.0.co;2

Ebben, W. P., & Watts, P. B. (1998). A review of combined weight training and plyometric training modes: Complex training. *Strength and Conditioning Journal*, *20*(5), 18. https://doi.org/10.1519/1073-6840(1998)020<0018:arocwt>2.3.co;2

Ebben, W. P., Fauth, M. L., Garceau, L. R., & Petushek, E. J. (2011). Kinetic quantification of plyometric exercise intensity. *Journal of Strength and Conditioning Research*, *25*(12), 3288–3298. https://doi.org/10.1519/jsc.0b013e31821656a3

Ebben, W. P., Simenz, C., & Jensen, R. L. (2008). Evaluation of plyometric intensity using electromyography. *Journal of Strength and Conditioning Research*, *22*(3), 861–868. https://doi.org/10.1519/jsc.0b013e31816a834b

Ebben, W. P., VanderZanden, T., Wurm, B. J., & Petushek, E. J. (2010). Evaluating plyometric exercises using time to stabilization. *Journal of Strength and Conditioning Research*, *24*(2), 300–306. https://doi.org/10.1519/jsc.0b013e3181cbaadd

Eliakim, A. (2014). Improving anaerobic fitness in young basketball players: Plyometric vs. specific sprint training. *Journal of Athletic Enhancement*, *03*(03). https://doi.org/10.4172/2324-9080.1000148

Ettema, G. J. (1996). Mechanical efficiency and efficiency of storage and release of series elastic energy in skeletal muscle during stretch–shorten cycles. *Journal of Experimental Biology*, *199*(9), 1983–1997. https://doi.org/10.1242/jeb.199.9.1983

Fatouros, I. G., Jamurtas, A. Z., Leontsini, D., Taxildair, K., Aggelousis, N., Kostopoul, N., & Buckenmeyer, P. (2000). Evaluation of plyometric exercise training, weight training, and their combination on vertical jumping performance and leg strength. *Journal of Strength and Conditioning Research*, *14*(4), 470–476. https://doi.org/10.1519/00124278-200011000-00016

Fauth, M. L., Petushek, E. J., Feldmann, C. R., Hsu, B. E., Garceau, L. R., Lutsch, B. N., & Ebben, W. P. (2010). Reliability of surface electromyography during maximal voluntary isometric contractions, jump landings, and cutting. *Journal of Strength and Conditioning Research*, *24*(4), 1131–1137. https://doi.org/10.1519/jsc.0b013e3181cc2353

Fouré, A., Nordez, A., McNair, P., & Cornu, C. (2010). Effects of plyometric training on both active and passive parts of the plantarflexors series elastic component stiffness of muscle–tendon complex. *European Journal of Applied Physiology*, *111*(3), 539–548. https://doi.org/10.1007/s00421-010-1667-4

Gabriel, D. A., Kamen, G., & Frost, G. (2006). Neural adaptations to resistive exercise. *Sports Medicine*, *36*(2), 133–149. https://doi.org/10.2165/00007256-200636020-00004

Gearhart, R. F., Goss, F. L., Lagally, K. M., Jakicic, J. M., Gallagher, J., & Roberson, R. J. (2001). Standardized scaling procedures for rating perceived exertion during resistance exercise. *Journal of Strength and Conditioning Research*, *15*(3), 320–325. https://doi.org/10.1519/00124278-200108000-00010

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

Hakkukinen, K., Komi, P. V., & Alen, M. (1985). Effect of explosive type strength training on isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of leg extensor muscles. *Acta Physiologica Scandinavica*, *125*(4), 587–600. https://doi.org/10.1111/j.1748-1716.1985.tb07760.x

Hammami, M., Bragazzi, N. L., Hermassi, S., Gaamouri, N., Aouadi, R., Shephard, R. J., & Chelly, M. S. (2020). The effect of a sand surface on physical performance responses of junior male handball players to plyometric training. *BMC Sports Science, Medicine and Rehabilitation*, *12*(1). https://doi.org/10.1186/s13102-020-00176-x

Hammami, M., Gaamouri, N., Shephard, R. J., & Chelly, M. S. (2019). Effects of contrast strength vs. plyometric training on lower-limb explosive performance, ability to change direction and neuromuscular adaptation in soccer players. *Journal of Strength and Conditioning Research*, *33*(8), 2094–2103. https://doi.org/10.1519/jsc.0000000000002425

Hedayatpour, N., & Falla, D. (2015). Physiological and neural adaptations to eccentric exercise: Mechanisms and considerations for training. *BioMed Research International*, *2015*, 1–7. https://doi.org/10.1155/2015/193741

Herrington, L., Munro, A., & Comfort, P. (2015). A preliminary study into the effect of jumping–landing training and strength training on frontal plane projection angle. *Manual Therapy*, *20*(5), 680–685. https://doi.org/10.1016/j.math.2015.04.009

Jamurtas, A. Z., Fatouros, I. G., Buckenmeyer, P., Kokkinidis, E., Taxildaris, K., Kambas, A., & Kyriazis, G. (2000). Effects of plyometric exercise on muscle soreness and plasma creatine kinase levels and its comparison with eccentric and concentric exercise. *The Journal of Strength and Conditioning Research*, *14*(1), 68. https://doi.org/10.1519/1533-4287(2000)014<0068:eopeom>2.0.co;2

Jarvis, M. M., Graham-Smith, P., & Comfort, P. (2016). A methodological approach to quantifying plyometric intensity. *Journal of Strength and Conditioning Research*, *30*(9), 2522–2532. https://doi.org/10.1519/jsc.0000000000000518

Jeffreys, M. A., De Ste Croix, M. B. A., Lloyd, R. S., Oliver, J. L., & Hughes, J. D. (2019). The effect of varying plyometric volume on stretch-shortening cycle capability in collegiate male rugby players. *Journal of Strength and Conditioning Research*, *33*(1), 139–145. https://doi.org/10.1519/jsc.0000000000001907

Jensen, R. L., & Ebben, W. P. (2007). Quantifying plyometric intensity via rate of force development, Knee Joint, and ground reaction forces. *The Journal of Strength and Conditioning Research*, *21*(3), 763. https://doi.org/10.1519/r-18735.1

Kayantaş, I., & Söyler, M. (2020). Effect of Plyometric Training on Speed Parameters (A Meta-Analysis Study). *International Journal of Applied Exercise Physiology*, *9*(8), 117–130.

Keshishian, H., Broadie, K., Chiba, A., & Bate, M. (1996). The drosophila neuromuscular junction: A model system for studying synaptic development and function. *Annual Review of Neuroscience*, *19*(1), 545–575. https://doi.org/10.1146/annurev.ne.19.030196.002553

Khlifa, R., Aouadi, R., Hermassi, S., Chelly, M. S., Jlid, M. C., Hbacha, H., & Castagna, C. (2010). Effects of a plyometric training program with and without added load on jumping ability in basketball players. *Journal of Strength and Conditioning Research*, *24*(11), 2955–2961. https://doi.org/10.1519/jsc.0b013e3181e37fbe

Khodaei, K., Mohammadi, A., & Badri, N. (2017). A comparison of assisted, resisted, and common plyometric training modes to enhance sprint and Agility Performance. *The Journal of Sports Medicine and Physical Fitness*, *57*(10). https://doi.org/10.23736/s0022-4707.17.06901-8

Khodaei, K., Mohammadi, A., & Hamedinia, M. R. (2017). Evaluation of plyometric exercises intensity using ratings of perceived exertion scale. *Medicina Dello Sport*, *70*(3). https://doi.org/10.23736/s0025-7826.17.02952-0

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *Journal of Biomechanics*, *33*(10), 1197–1206. https://doi.org/10.1016/s0021-9290(00)00064-6

Komi, P. V. (2003). Stretch-shortening cycle. *Strength and Power in Sport*, 184–202. https://doi.org/10.1002/9780470757215.ch10

Kubo, K., Morimoto, M., Komuro, T., Yata, H., Tsunoda, N., Kanehisa, H., & Funkunaga, T. (2007). Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Medicine & Science in Sports & Exercise*, *39*(10), 1801–1810. https://doi.org/10.1249/mss.0b013e31813e630a

Lockie, R. G., Murphy, A., & Janse de Jonge, X. (2011). Quantifying training load for free sprint, resisted sprint, plyometrics and weights training with session-RPE in field sport athletes. *Journal of Strength and Conditioning Research*, *25*. https://doi.org/10.1097/01.jsc.0000395600.19274.ec

Luebbers, P. E., Potteiger, J. A., Hulver, M. W., Thyfault, J. P., Carper, M. J., & Lockwood, R. H. (2003). Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *Journal of Strength and Conditioning Research*, *17*(4), 704–709. https://doi.org/10.1519/00124278-200311000-00013

Maffiuletti, N. A., Dugnanl, S., Folz, M., Di Pierno, E., & Mauro, F. (2002). Effect of combined electrostimulation and plyometric training on vertical jump height. *Medicine & Science in Sports & Exercise*, *34*(10), 1638–1644. https://doi.org/10.1097/00005768-200210000-00016

Malisoux, L., Francaux, M., Nielens, H., & Theisen, D. (2006). Stretch-shortening cycle exercises: An effective training paradigm to enhance power output of human single muscle fibers. *Journal of Applied Physiology*, *100*(3), 771–779. https://doi.org/10.1152/japplphysiol.01027.2005

Mankar, S. S. (2020). A comparative study of effect of sand and land plyometric training on speed and explosive power among basketball players. *Journal of Sports Science and Nutrition*, *1*(2), 37–39. https://doi.org/E-ISSN: 2707-7020

Markovic, G., & Mikulic, P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sports Medicine*, *40*(10), 859–895. https://doi.org/10.2165/11318370-000000000-00000

Masamoto, N., Larson, R., Gates, T., & Faigenbaum, A. (2003). Acute effects of plyometric exercise on maximum squat performance in male athletes. *Journal of Strength and Conditioning Research*, *17*(1), 68–71. https://doi.org/10.1519/00124278-200302000-00011

McKinlay, B. J., Wallace, P., Dotan, R., Long, D., Tokuno, C., Gabriel, D. A., & Falk, B. (2018). Effects of plyometric and resistance training on muscle strength, explosiveness, and neuromuscular function in young adolescent soccer players. *Journal of Strength and Conditioning Research*, *32*(11), 3039–3050. https://doi.org/10.1519/jsc.0000000000002428

Miller, M. G., Berry, D. C., Bullard, S., & Gilders, R. (2002). Comparisons of land-based and aquatic-based plyometric programs during an 8-week training period. *Journal of Sport Rehabilitation*, *11*(4), 268–283. https://doi.org/10.1123/jsr.11.4.268

Mirzaei, B., Norasteh, A. A., & Asadi, A. (2013). Neuromuscular adaptations to plyometric training: Depth jump vs. Countermovement jump on Sand. *Sport Sciences for Health*, *9*(3), 145–149. https://doi.org/10.1007/s11332-013-0161-x

Moritani, T., & deVries, H. A. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med Rehabil*, *58*(3), 115–130.

Makaruk, H., Starzak, M., Bogusz, S., Maciej, C., & Nenad, S. (2020). The effects of assisted and resisted plyometric training programs on vertical jump performance in adults: a systematic review and meta-analysis. *Journal of Sports Science & Medicine*, 19(2), 347–357.

Nagaraja, Y., & Gajanana Prabhu, B. (2017). Effect of eight weeks land and sand based plyometric training on selected physical and physiological variables. *International Journal of Physical Education, Fitness and Sports*, *6*(2), 40–45. https://doi.org/10.26524/2017.06.02.9

Newton, R. U., & McEvoy, K. I. (1994). Baseball throwing velocity: A comparison of medicine ball training and weight training. *The Journal of Strength and Conditioning Research*, *8*(3), 198. https://doi.org/10.1519/1533-4287(1994)008<0198:btvaco>2.3.co;2

Öz, E., Çelenk, B., Hayirli, Özkan, & Öz, E. (2019). The effect of eight-week plyometric training on Agilty in male volleyball players. *The Online Journal of Recreation and Sport*, *Volume 8*(Volume 8 Issue 1), 23–32. https://doi.org/10.22282/ojrs.2019.44

Ozen, G., Atar, O., & Koc, H. (2020). The effects of a 6-week plyometric training programme on sand versus wooden parquet surfaces on the physical performance parameters of well-trained young basketball players. *Montenegrin Journal of Sports Science and Medicine*, *9*(1), 27–32. https://doi.org/10.26773/mjssm.200304

Palma-Muñoz, I., Ramírez-Campillo, R., Azocar-Gallardo, J., Álvarez, C., Asadi, A., Moran, J., & Chaabene, H. (2021). Effects of progressed and nonprogressed volume-based overload plyometric training on components of physical fitness and body composition variables in youth male basketball players. *Journal of Strength and Conditioning Research*, *Publish Ahead of Print*. https://doi.org/10.1519/jsc.0000000000002950

Ploeg, A. H., Miller, M. G., Holcomb, W. R., O’Donoghue, J., Berry, D., & Dibbet, T. J. (2010). The effects of high volume aquatic plyometric training on vertical jump, muscle power, and torque. *International Journal of Aquatic Research and Education*, *4*(1). https://doi.org/10.25035/ijare.04.01.06

Prieske, O., Muehlbauer, T., Mueller, S., Krueger, T., Kibele, A., Behm, D. G., & Granacher, U. (2013). Effects of surface instability on neuromuscular performance during drop jumps and landings. *European Journal of Applied Physiology*, *113*(12), 2943–2951. https://doi.org/10.1007/s00421-013-2724-6

Radcliffe, J. C., & Farentinos, R. C. (2015). *High-powered plyometrics*. Human Kinetics Champaign, IL.

Radin, E. L. (2009). Role of muscles in protecting athletes from injury. *Acta Medica Scandinavica*, *220*(S711), 143–147. https://doi.org/10.1111/j.0954-6820.1986.tb08943.x

Ramírez-Campillo, R., Andrade, D. C., & Izquierdo, M. (2013). Effects of plyometric training volume and training surface on explosive strength. *Journal of Strength and Conditioning Research*, *27*(10), 2714–2722. https://doi.org/10.1519/jsc.0b013e318280c9e9

Ramirez-Campillo, R., García-Pinillos, F., García-Ramos, A., Yanci, J., Gentil, P., Chaabene, H., & Granacher, U. (2018). Effects of different plyometric training frequencies on components of physical fitness in amateur female soccer players. *Frontiers in Physiology*, *9*. https://doi.org/10.3389/fphys.2018.00934

Ramírez-Campillo, R., Henríquez-Olguín, C., Burgos, C., Andrade, D. C., Zapata, D., Martínez, C., Álvarez, C., Baez, E. I., Castro-Sepúlveda, M., Peñailillo, L., & Izquierdo, M. (2015). Effect of progressive volume-based overload during plyometric training on explosive and endurance performance in young soccer players. *Journal of Strength and Conditioning Research*, *29*(7), 1884–1893. https://doi.org/10.1519/jsc.0000000000000836

Rassier, D. E., MacIntosh, B. R., & Herzog, W. (1999). Length dependence of active force production in skeletal muscle. *Journal of Applied Physiology*, *86*(5), 1445–1457. https://doi.org/10.1152/jappl.1999.86.5.1445

Resh, T., T, J., Meeran, R. B., & Kumar, V. P. R. S. (2017). Effect of plyometric exercise training on vertical jump height between ground and sand surface in male volleyball players. *International Journal of Pharma and Bio Sciences*, *8*(3). https://doi.org/10.22376/ijpbs.2017.8.3.b370-376

Rezaimanesh, D., Amiri-Farsani, P., & Saidian, S. (2011). The effect of a 4 week plyometric training period on lower body muscle EMG changes in futsal players. *Procedia - Social and Behavioral Sciences*, *15*, 3138–3142. https://doi.org/10.1016/j.sbspro.2011.04.260

Rhode, A., & Berry, D. (2017). Effects of aquatic and land plyometrics on athletic performance: A systematic review. *International Journal of Aquatic Research and Education*, *10*(3). https://doi.org/10.25035/ijare.10.03.03

Robinson, L. E., Devor, S. T., Merrick, M. A., & Buckworth, J. (2003). The effects of land versus aquatic plyometrics on power, torque, Velocity, and muscle soreness. *Medicine & Science in Sports & Exercise*, *35*(Supplement 1). https://doi.org/10.1097/00005768-200305001-01354

Robinson, L. E., Devor, S. T., Merrick, M. A., & Buckworth, J. (2004). The effects of land vs. aquatic plyometrics on power, torque, velocity, and muscle soreness in women. *The Journal of Strength and Conditioning Research*, 18(1), 84. https://doi.org/10.1519/1533-4287(2004)018%3C0084:teolva%3E2.0.co;2

Rode, C., Siebert, T., Herzog, W., & Blickhan, R. (2009). The effects of parallel and series elastic components on the active Cat Soleus Force-length relationship. *Journal of Mechanics in Medicine and Biology*, *09*(01), 105–122. https://doi.org/10.1142/s0219519409002870

Saeterbakken, A. H., Stien, N., Andersen, V., Scott, S., Cumming, K. T., Behm, D. G., Granacher, U., & Prieske, O. (2022). The effects of trunk muscle training on physical fitness and sport-specific performance in young and adult athletes: A systematic review and meta-analysis. *Sports Medicine*, *52*(7), 1599–1622. https://doi.org/10.1007/s40279-021-01637-0

Sáez-Sáez de Villarreal, E., Requena, B., & Newton, R. U. (2010). Does plyometric training improve strength performance? A meta-analysis. *Journal of Science and Medicine in Sport*, *13*(5), 513–522. https://doi.org/10.1016/j.jsams.2009.08.005

Sanborn, C. F. (2006). Aquatic plyometric training increases vertical jump in female volleyball players. *Yearbook of Sports Medicine*, *2006*, 155–156. https://doi.org/10.1016/s0162-0908(08)70358-1

Sankey, S. P., Jones, P. A., & Bampouras, T. M. (2008). Effects of Two Plyometric Training Programs of Different Intensity on Vertical Jump Performance in High

School Athletes . *Serbian Journal of Sports Sciences*, *2*(4), 123–130. https://doi.org/1820-6301

Schenau, G. J., Bobbert, M. F., & de Haan, A. (1997). Does elastic energy enhance work and efficiency in the stretch-shortening cycle? *Journal of Applied Biomechanics*, *13*(4), 389–415. https://doi.org/10.1123/jab.13.4.389

Schmidtbleicher, G. D., & Frick, U. (1988). Effects of stretch shortening time training on the performance capability and innervation characteristics of leg extensor muscles. *Biomechanics XI-A*, *7-A*, 185–189.

Semmler, J. G., & Nordstrom, M. A. (1998). Motor Unit Discharge and force tremor in skill- and strength-trained individuals. *Experimental Brain Research*, *119*(1), 27–38. https://doi.org/10.1007/s002210050316

Shah, S. (2012). Plyometric exercises. *International Journal of Health Sciences and Research*, *2*(1), 115-126.

Singh, A., Boyat, A. K., & Sandhu, J. S. (2015). Effect of a 6 week plyometric training program on Agility, vertical jump height and peak torque ratio of Indian taekwondo players. *Sports and Exercise Medicine - Open Journal*, *1*(2), 42–46. https://doi.org/10.17140/semoj-1-107

Singh, A., Sakshi, G., & Singh, S. J. (2014). Effect of plyometric training on sand versus grass on muscle soreness and selected sport-specific performance variables in hockey players. *Journal of Human Sport and Exercise*, *9*(1), 59–67. https://doi.org/10.4100/jhse.2014.91.07

Smith, J., & Clark, J. (2014). *Vertical Foundations: The physiology, biomechanics and techniques of explosive vertical jumping*. Just Fly Sports.

Sole, S., Ramírez-Campillo, R., Andrade, D. C., & Sanchez-Sanchez, J. (2021). Plyometric jump training effects on the physical fitness of individual-sport athletes: A systematic review with meta-analysis. *PeerJ*, *9*. https://doi.org/10.7717/peerj.11004

Stemm, J. D., & Jacobson, B. H. (2007). Comparison of land- and aquatic-based plyometric training on vertical jump performance. *The Journal of Strength and Conditioning Research*, *21*(2), 568. https://doi.org/10.1519/r-20025.1

Taube, W., Leukel, C., & Gollhofer, A. (2012). How neurons make US jump. *Exercise and Sport Sciences Reviews*, *40*(2), 106–115. https://doi.org/10.1097/jes.0b013e31824138da

Taube, W., Leukel, C., Lauber, B., & Gollhofer, A. (2011). The drop height determines neuromuscular adaptations and changes in jump performance in stretch-shortening cycle training. *Scandinavian Journal of Medicine & Science in Sports*, *22*(5), 671–683. https://doi.org/10.1111/j.1600-0838.2011.01293.x

Toumi, H., Thiery, C., Maitre, S., Martin, A., Vanneuville, G., & Poumarat, G. (2001). Training effects of amortization phase with eccentric/concentric variations - the vertical jump. *International Journal of Sports Medicine, 22*(8), 605–610. https://doi.org/10.1055/s-2001-18525

Turna, B., Sahan, A., & Yilmaz, B. (2019). The acute effects of dynamic and static stretching on tennis serve targeting performance. *Journal of Education and Training Studies*, *7*(4), 123. https://doi.org/10.11114/jets.v7i4.4058

Turner, A. N., & Jeffreys, I. (2010). The stretch-shortening cycle: Proposed mechanisms and methods for enhancement. *Strength & Conditioning Journal*, *32*(4), 87–99. https://doi.org/10.1519/ssc.0b013e3181e928f9

Van Lieshout, K. G., Anderson, J. G., Shelburne, K. B., & Davidson, B. S. (2014). Intensity rankings of plyometric exercises using joint power absorption. *Clinical Biomechanics*, *29*(8), 918–922. https://doi.org/10.1016/j.clinbiomech.2014.06.015

Verkhoshansky, Y. V., & Lazarev, V. V. (1989). From the Eastern Bloc: Principles of planning speed and strength/speed endurance training in sports. *National Strength & Conditioning Association Journal*, *11*(2), 58. https://doi.org/10.1519/0744-0049(1989)011<0058:popsas>2.3.co;2

Vossen, J. F., Kramer, J. F., Burke, D. G., & Vossen, D. P. (2000). Comparison of dynamic push-up training and plyometric push-up training on upper-body power and strength. *The Journal of Strength and Conditioning Research*, *14*(3), 248. https://doi.org/10.1519/1533-4287(2000)014<0248:codput>2.0.co;2

Wang, M.-H., Chen, K.-C., Hung, M.-H., Chang, C.-Y., Ho, C.-S., Chang, C.-H., & Lin, K.-C. (2020). Effects of plyometric training on surface electromyographic activity and performance during blocking jumps in College Division I Men’s Volleyball Athletes. *Applied Sciences*, *10*(13), 4535. https://doi.org/10.3390/app10134535

Wathen, D. (1993). Position statement: Explosive/plyometric exercises. *National Strength & Conditioning Association Journal*, *15*(3), 16. https://doi.org/10.1519/0744-0049(1993)015<0016:epe>2.3.co;2

Watkins, C. M., Gill, N. D., Maunder, E., Downes, P., Young, J. D., McGuigan, M. R., & Storey, A. G. (2020). The effect of low-volume preseason plyometric training on Force-velocity profiles in semiprofessional rugby union players. *Journal of Strength and Conditioning Research*, *35*(3), 604–615. https://doi.org/10.1519/jsc.0000000000003917

Wilk, K. E., Voight, M. L., Keirns, M. A., Gambetta, V., Andrews, J. R., & Dillman, C. J. (1993). Stretch-shortening drills for the upper extremities: Theory and clinical application. *Journal of Orthopaedic & Sports Physical Therapy*, *17*(5), 225–239. https://doi.org/10.2519/jospt.1993.17.5.225

Yanci, J., Castillo, D., Iturricastillo, A., Ayarra, R., & Nakamura, F. Y. (2017). Effects of two different volume-equated weekly distributed short-term plyometric training programs on Futsal Players' physical performance. *Journal of Strength and Conditioning Research*, *31*(7), 1787–1794. https://doi.org/10.1519/jsc.0000000000001644

Yanci, J., Los Arcos, A., Camara, J., Castillo, D., García, A., & Castagna, C. (2016). Effects of horizontal plyometric training volume on soccer players' performance. *Research in Sports Medicine*, *24*(4), 308–319. https://doi.org/10.1080/15438627.2016.1222280

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effect of Instructions on characteristics of Countermovement and Drop Jump Performance. *Journal of Strength and Conditioning Research*, *9*(4), 232–236. https://doi.org/10.1519/00124278-199511000-00005