EFFECTS OF 8-WEEK NONLINEAR PERIODIZED TRAINING PROGRAM ON PHYSICAL FITNESS AND CONTRIBUTORS OF FUNCTIONAL KNEE JOINT STABILITY IN 101ST DIVISION ARMY SOLDIERS

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Army soldiers engage in various types of vigorous physical fitness training daily and unintentional musculoskeletal injuries are quite common. Based on previous research, training principles, and theories, a training program was developed to target components of physical fitness and improve neuromuscular and biomechanical factors that are important to knee joint stability. The purpose of this study was to evaluate the effects of an 8-week nonlinear periodized training program on physical fitness and contributors of functional knee joint stability in 101st Division Army soldiers.

Due to the timing of the study, the duration of this training overlapped with the soldiers' deployment preparation schedule. As a result, of 52 soldiers who were initially enrolled (28 in the experimental group and 24 in the control group), only 26 soldiers completed the study (23 in the experimental group and 13 in the control group). Knee and hip strength, knee joint rate of force development, knee proprioception, and knee and hip neuromuscular and biomechanical characteristics during a stop-jump and a drop-jump task were measured before and after the intervention.

There were no statistically significant findings for any dependent variables. High attrition rate and the lack of training exposure were the confounding factors for this study. Future studies must consider soldiers' training/deployment schedules to avoid those confounding factors and should monitor the daily training exposure and types of training for the control group.

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PREFACE

This study was conducted in conjunction with the larger research project. I have been fortunate to work on the project and to coordinate laboratory activities at the Human Performance Research Center at Fort Campbell, KY, the home of the 101st Airborne Division (Air Assault) for past three years. It has been my honor working with the most patriotic and bravest soldiers in the world. I wish all soldiers the best. “Air Assault”!

This dissertation is not just a study; it reflects the history of my personal development and growth to become a better person and researcher during my term with the University and Laboratory. I thank the committee members: Dr. Tim Sell, Dr. John Abt, Dr. Elaine Rubinstein, Dr. Freddie Fu, COL Russell Rowe, and Dr. Scott Lephart for their feedback and valuable insight. I would like to extend a special acknowledgement to the committee chair, Dr. Lephart, who challenges me to achieve excellence in research and to build professional relationships and leadership. My job assignment at Fort Campbell has been one of the most valuable learning experiences I have ever had in my life.

There are many fellow students, co-workers, military personnel, friends, and family to whom I express my appreciation. I would like to recognize my wife, Wakana Nagai, my daughter, Hana Nagai, and my parents, Makoto Nagai and Eiko Nagai for their everlasting support.

1.0 INTRODUCTION

1.1 OVERVIEW

Army soldiers engage in various types of vigorous physical fitness training daily, including running, marching, and muscular strength and endurance exercises.[1] As a result, unintentional musculoskeletal injuries are quite common.[2] The lower extremity and back are the most frequently injured body parts and often result in long-term disability and ultimately discharge, costing more than a billion dollars yearly for compensation.[3-7] Army epidemiological studies have identified several risk factors for injury: poor physical fitness, age, smoking history, high running/marching mileage, and high body-mass index.[2, 4, 8-13] Similarly, epidemiological studies on the civilian population have identified the following biomechanical and neuromuscular risk factors: lower extremity landing kinematics, proprioception, and neuromuscular control.[14-17] In order to develop and design the most desirable physical training program that targets physical fitness and neuromuscular and biomechanical risk factors, one must first understand the physiology of physical fitness, the modifiable biomechanical and neuromuscular risk factors, and other potential contributors to functional joint stability. A well-designed training program would induce favorable adaptations on the cardiovascular and musculoskeletal systems to enhance physical fitness and functional joint stability.

Therefore, the purpose of this study was to evaluate the effects of an 8-week nonlinear periodized training program on physical fitness and contributors to functional knee joint stability on 101st Division Army soldiers. Physical fitness was tested utilizing the standard Army Physical Fitness Test (APFT), which includes the maximum number of push-ups and sit-ups performed in 2 minutes and the 2 mile run time. Functional joint stability (FJS) is defined as possessing adequate joint stability to perform functional activity and results from the interaction between static and dynamic components.[18, 19] The interaction between the static and dynamic components is very complex and there is no single variable that can be measured or used to define FJS. Over decades of research, however, potential contributors of FJS have been identified: biomechanical factors, neuromuscular control, strength, and proprioception. These contributors were evaluated as dependant variables in this study.

Throughout this manuscript, anterior cruciate ligament (ACL) injury prevention studies are used as a model for understanding potential contributors of FJS and the effects of prevention programs. The main reason for selecting ACL injury prevention studies as the model is that the ACL is the most commonly studied structure in the lower extremity and possesses unique features such as non-contact injury mechanisms, higher injury rates in female athletes, unique adaptations with ACL-deficiency (ACL-D), and availability of various injury prevention programs. It is possible to apply the concept of FJS to any joint and different joint pathologies, although there is some information very specific to the ACL.

1.1.1 Physiologic Basis of Functional Joint Stability

Functional joint stability is defined as possessing adequate joint stability to perform functional activity and results from the interaction between static and dynamic components.[18, 19]

As separate entities, neither the mechanical nor dynamic restraints act alone in providing FJS; instead, a mechanical-dynamic restraint interaction is required to achieve a stable joint. The interaction between the static and dynamic components of functional stability is mediated by the sensorimotor system. The sensorimotor system encompasses all of the sensory, motor, and central integration and processing components of the central nervous system (CNS) involved in maintaining FJS.[20] The importance of sensory information, central processing and integration, and neuromuscular control to achieve a stable joint is widely recognized (Figure 1).

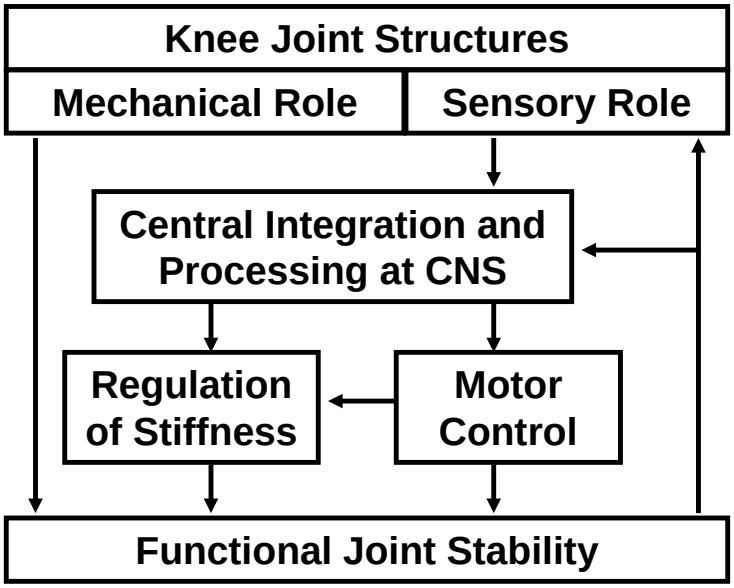


Figure 1. Functional Joint Stability Paradigm

In order to achieve FJS during dynamic movements on various surface conditions or after the loss of ligamentous support, the human body has to adapt by constantly adjusting and altering neuromuscular and biomechanical factors.[21-26] This highly adaptable nature of motor control and coordination is largely dependent upon the accuracy and sensitivity of proprioceptive information derived from the peripheral mechanoreceptors.[27-29]

1.1.2 The Role of Proprioception in Functional Joint Stability

There are several types of afferent sensory organs (mechanoreceptors) found in the various knee joint structures: Ruffini endings, Pacinian Corpuscles, Golgi tendon organ-like endings, free nerve endings, muscle spindles, and Golgi tendon organs (GTO). The signals from the Ruffini endings contain information about static joint position, intra-articular pressure, and the amplitude and velocity of joint rotations.[30] Pacinian corpuscles function purely as dynamic mechanoreceptors.[31] Golgi tendon organ-like endings are active towards the end range of joint motion.[32] Free nerve endings become active when the articular tissue is subjected to damaging mechanical deformations.[33] Muscle spindles are oriented in parallel with the skeletal muscle fibers, encoding the event of muscle stretch and the rate of passive elongation.[34] In contrast, GTOs are aligned in series within the musculotendinous junctions, encoding the stretch on the tendon generated by the total force of a given muscle during contraction.[34]

Muscle spindles and GTOs play an important role in regulating muscle tone and joint stiffness, especially during dynamic tasks.[35, 36] As the main contributor to joint stiffness, muscle stiffness is defined as the ratio of change in force per change in length and consists of two components: an intrinsic and a reflex-mediated component.[37] The intrinsic component is dependent on the viscoelastic properties of the muscle and the number of actin-myosin bonds while the reflex-mediated component is dependent on the excitability of the alpha motor neuron pool.[38-40] The gamma-muscle spindle system can change the sensitivity and threshold of the alpha motor neuron pools, regulating the amount of intrinsic muscle stiffness; it is influenced by the mechanoreceptors and integrates with descending and reflex input (Figure 2).[40, 41]

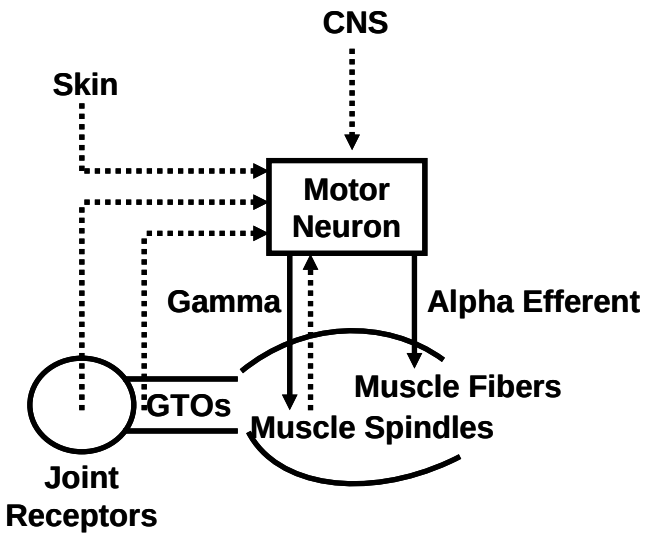


Figure 2. Influences on Alpha and Gamma-Motor Neuron System

Increased muscle stiffness has two advantages: increased resistance against sudden joint displacement and enhanced time to transmit loads to the muscle spindles, resulting in quicker initiation of reflexive activity.[42, 43] The regulation of muscle stiffness through the gamma-muscle spindle system plays an essential role in proprioception and, along with integration in the CNS, elicits appropriate neuromuscular control and achieves FJS.[38-40]

1.1.3 The Role of Neuromuscular Control in Functional Joint Stability

Neuromuscular control is defined as the unconscious activation of dynamic restraints occurring in preparation for, and in response to, joint motion and loading for the purpose of maintaining and restoring FJS.[44] A combination of feedforward and feedback neuromuscular control is used: feedback control uses information about the current state of a person and the external environment to modify muscle activity and feedforward control does not require peripheral receptors, instead modifying muscle activity by anticipating the external environment.[35]

There are two fundamentally different ways that the CNS uses sensory feedback. First, the afferent feedback, a part of normal movement, is integrated with motor commands in the activation of muscles. This feedback is anticipated by the CNS and built in to the motor programs controlling movement.[45] Second, the reflex-mediated component is generated when an unexpected change occurs in the sensory feedback. These reflexes constitute error signals, which aim to correct the ongoing movements and avoid falling. Although the reflex signals may not be sufficient to correct the movement, the error signals inform the higher structures of the brain about the disturbance and help the brain adjust the motor programs (motor learning) in addition to the regulation of stiffness via the gamma-muscle spindle.[45, 46]

Feedforward control can achieve joint stability through both short-range stiffness and muscle pre-activation. Activated muscles provide resistance against sudden stretch or joint perturbation. Since the muscles are already active at the time of perturbation, the time to reach peak force is very short (less than 50ms) and can provide a substantial response to the perturbation.[47, 48] This fast production of force, short-range stiffness, is considered to be the first line of defense.[49, 50] Muscle pre-activation (onset time and amplitude) is modified depending on the external environment. For example, during a drop-landing task from a tall box, when potential injurious forces are greater, a person can have earlier onset and greater activation of the quadriceps prior to foot contact compared with a small box drop-landing.[26] Thus, the muscles surrounding a joint adequately can anticipate musculoskeletal needs and achieve FJS.

1.2 RESEARCH DESIGN AND INTERVENTION

1.2.1 Research Design

A 2 x 2 mixed design ANOVA was used for the study. The first independent variable was the group. There were two levels on the group: control and experimental. The second independent variable was time. There were also two levels on time: pre-training and post-training.

1.2.2 Intervention Programs

Subjects in the experimental group participated in an 8-week nonlinear periodized training program. The design of this program was carefully considered in order to cover resistance training for strength and power; endurance training for basic physical fitness and road-march capability; quickness, agility, and speed training for mission-ready capability; and supplemental stretching and resistance training for injury prevention and stress reduction. In addition, team unity and leadership were emphasized by creating different levels/goal/intensities at each station. At large, each workout session consisted of a warm-up, main workout, supplemental exercises, and conclusion. Dynamic warm-up was followed by the main workout which covered five main types of training: two types of resistance training (strength and power) and three types of endurance training (speed, interval, and long) in order to optimize all areas of tactical performance (Figure 3).

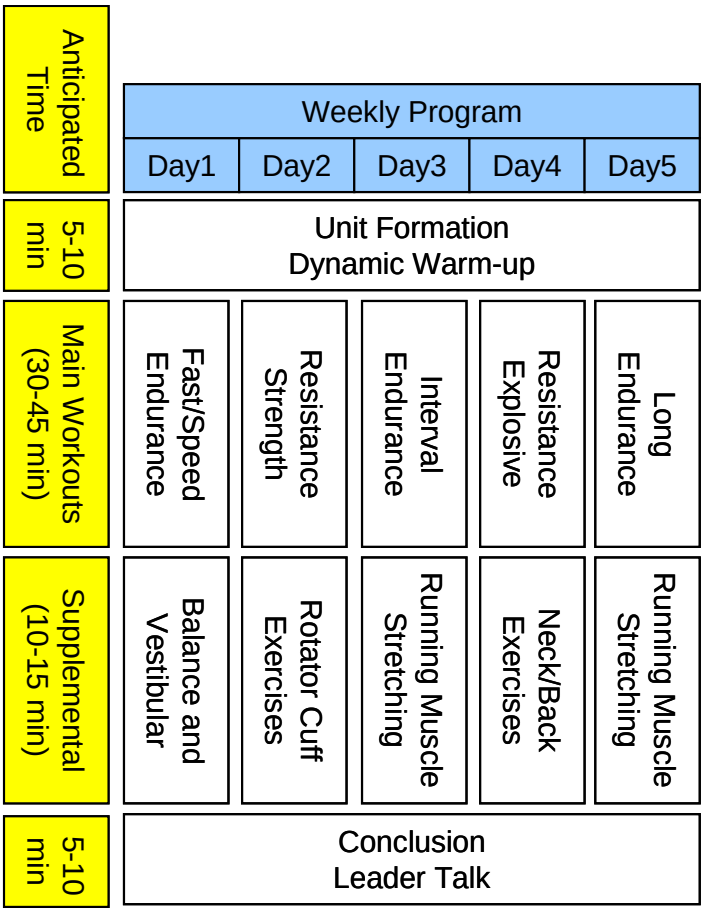


Figure 3. Daily and Weekly Training Schedule

Training volume (sets and repetitions), intensity, and rest varied daily depending on the purpose of each workout session in a nonlinear manner (Figure 3). Overall volume, intensity, rest, and run or march distance also varied over every 2 week phase: phase I focused on general adaptation and introduction; phase II focused on a gradual increase on sets and repetitions; phase III focused on a gradual increase in intensity and less volume; and phase IV focused on the final preparation for the tests and tapering. Long runs and marches were progressed gradually from week #1 to week #8 (Figure 4).

Pre-Training: Tests and Intro/Teaching
Week 1-2: Phase I General Adaptation
Week 3-4: Phase II Higher Volume
Week 5-6: Phase III Higher Intensity
Week 7-8: Phase IV Peak and Taper
Post-Training: Tests and Recovery

Figure 4. Bi-weekly Progression Model

Strength training and resistance exercises have been associated with neural and muscular adaptations that improve strength. Neural adaptations include increased activation of the agonist muscle and spinal cord connections, improved coordination, and muscular adaptations, including muscular hypertrophy and an increased specific tension.[51-53] From a FJS point of view, increased strength is beneficial for both feedback and feedforward control. Increased muscle strength means greater stiffness per given muscle activation level, thereby potentially increasing protection of a joint from joint disrupting forces. It has been suggested that strength training can improve mechanical output by increasing efficiency of the central command.[54] Strength training has been shown to improve proprioception.[55]

Unstable surface exercises (balance and resistance exercises on unstable surface) have been shown to improve postural stability, knee strength, and landing mechanics.[56-58] A combination of aggressive balance exercises can improve the rate of force development (RFD), leg stiffness, and muscle activation of both knee flexor and extensor muscles as measured by electromyography (EMG).[59-63] Unstable surface exercises can exert a positive influence on the CNS, resulting in changes which are ideal for both injury prevention and optimal performance.[59-61, 64, 65]

Plyometric exercises are effective in reducing vertical ground reaction forces (GRF), improving knee extensor and flexor strength, improving the knee flexion/extension strength ratio, and increasing eccentric leg stiffness.[66-70] Plyometric exercises are effective in teaching proper techniques for landing and jumping.

Endurance training intensity and duration were mainly based on each subject's 2 mile run time and estimation of marathon race pace. Lactate threshold pace was used for long endurance and interval was used for interval endurance. The estimation of running speed and training intensity/duration closely followed the recommendations in a coaching book by Jack Daniels.[71]

1.3 STATEMENT OF PURPOSE

Soldiers face many physical challenges daily. In order to best prepare for the worst situations, various areas of physical fitness should be covered. The nonlinear periodization model was designed to improve all areas of physical fitness while preventing unnecessary musculoskeletal injuries. Previously, few studies have evaluated both physical fitness and the contributors to FJS. Therefore, the purpose of this study was to evaluate the effects of an 8-week nonlinear periodized training program on physical fitness and contributors to functional knee joint stability on 101st Division Army soldiers.

1.4 SPECIFIC AIMS AND RESEARCH HYPOTHESES

Specific Aim 1: To evaluate knee extension, knee flexion, and hip abduction strength measured in peak torque normalized by body mass before and after the intervention.

Research Hypothesis 1: There would be a greater improvement in knee extension, knee flexion, and hip abduction strength in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 2: To evaluate knee extension and flexion RFD measured in absolute values of torque in Newton-Meters per second and in normalized values of percentage of peak torque per second, both before and after the intervention.

Research Hypothesis 2: There would be a greater improvement in knee extension and flexion RFD in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 3: To evaluate knee extension and flexion conscious proprioception measured by threshold to detect passive motion (TTDPM) in degrees, both before and after the intervention.

Research Hypothesis 3: There would be a greater improvement in knee extension and flexion TTDPM in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 4: To evaluate knee flexion/extension, knee valgus/varus, and hip abduction/adduction joint angles at initial foot contact during a single-leg stop-jump task, before and after the intervention.

Research Hypothesis 4: There would be a greater improvement in knee flexion and hip abduction position and less valgus joint angle at initial foot contact in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 5: To evaluate knee separation distance measured in absolute separation distance (in centimeters) and in normalized separation distance (normalized to anterior superior iliac spine [ASIS] distance) at maximal knee flexion angle during the drop-jump task, before and after the intervention.

Research Hypothesis 5: There would be a greater improvement in knee separation distance, both absolute and normalized, in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 6: To evaluate knee extension/flexion joint stiffness measured in knee flexion moment over the range of knee flexion motion during the descending phase (from initial foot contact to maximum knee flexion) of the stop-jump task, before and after the intervention.

Research Hypothesis 6: There would be a greater improvement in knee flexion stiffness in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 7: To evaluate hamstrings and quadriceps co-contraction ratio measured by the average normalized EMG of the hamstrings over the average normalized EMG of the quadriceps during the pre-landing phase (150 millisecond prior to initial foot contact) of the stop-jump task, before and after the intervention.

Research Hypothesis 7: There would be a greater co-contraction ratio in the experimental group than in the control group as reflected by a significant group by time interaction.

Specific Aim 8: To evaluate Army Physical Fitness Test (push-ups in 2 minutes, sit-ups in 2 minutes, and 2 mile run time) before and after the intervention.

Research Hypothesis 8: The number of push-ups and sit-ups would increase and the 2 mile run time would be faster in the experimental group as compared to the control group as reflected by a significant group by time interaction.

2.0 REVIEW OF LITERATURE

2.1 MUSCULOSKELTAL INJURY DATA AND PHYSICAL FITNESS IN THE ARMY

2.1.1 Physical Training Principles and Guidelines Used by the US Army

In 1992, the headquarters of the Department of the Army published the field manual 21-20 as a standard physical training guideline for all US Army soldiers.[1] Although this manual covers the fundamental knowledge of cardiovascular fitness, body composition, muscular endurance, strength, and flexibility, unit leaders tend to focus on the APFT: push-ups, sit-ups, and 2 mile run (Figure 5).[1] Unfortunate consequences of such isolated training are the development of certain type of musculoskeletal injuries.

	FITT Factors Applied to Physical Conditioning Program				
	Cardiorespiratory Endurance	Muscular Strength	Muscular Endurance	Muscular Strength and Muscular Endurance	Flexibility
F	Frequency 3-5 times/week	3 times/week	3-5 times/week	3 times/week	Warm-up and Cool-down: Stretch before and after each exercise session Developmental Stretching: To improve flexibility, stretch 2-3 times/week
I	Intensity 60-90% HRR*	3-7 RM*	12+ RM	8-12 RM	Tension and slight discomfort, NOT PAIN
T	Time 20 minutes or more	The time required to do 3-7 repetitions of each exercise	The time required to do 12+ repetitions of each exercise	The time required to do 8-12 repetitions of each exercise	Warm-up and Cool-down Stretches: 10-15 seconds/stretch Developmental Stretches: 30-60 seconds/stretch
T	Type Running Swimming Cross-Country Skiing Rowing Bicycling Jumping Rope Walking/Hiking Stair Climbing	Free Weights Resistance Machines Partner-Resisted Exercises Body-Weight Exercises (Pushups/Situps/Pullups/Dips, etc.)			Stretching: Static Passive P.N.F.
	* HRR = Heart Rate Reserve	* RM = Repetition Maximum			

Figure 5. The Components of Physical Fitness and Exercise Guide by FM21-20[1]

2.1.2 Musculoskeletal Injuries in the Army

Army soldiers engage in various types of vigorous physical fitness training daily, including running, marching, and muscular strength and endurance exercises.[1] As a result, unintentional musculoskeletal injuries are quite common.[2] The lower extremity and back are the most frequently injured body parts, often resulting in long-term disability and ultimately discharge, and cost more than a billion dollar yearly for compensation.[3-7] After the implementation of a Standard Inpatient Data Record (SIDR) and the use of standard International Classification of Diseases-9 (ICD-9) codes in 1989, it becomes clear that injuries and

musculoskeletal conditions account the majority of hospitalizations, even during the time of the Gulf War.[72] Lauder and colleagues investigated sports and physical training injury hospitalizations in the Army from 1989 to 1994 and reported a total of 13,861 hospital admissions (38.2 and 18.3 injury rates per 10,000 person-years for males and females, respectively) and 29,435 lost duty days each year (13 and 11 days per injury for males and females, respectively).[3] A similar trend of high non-battle injuries has been reported during the Operation Iraqi Freedom.[73, 74] Sanders and colleagues conducted a survey of 15,459 soldiers who deployed to Iraq or Afghanistan during 2003-2004 and reported that non-battle injuries accounted for a third of all clinical visits. They also report that the common mechanisms of non-battle injuries were sports (23.0%), heavy loads (14.4%), jump/fall (13.7%), and other unspecified causes (42.6%).[73] According to the recent Medical Surveillance Monthly Report (MSMR), injury/poisoning, mental disorders, and musculoskeletal/connective tissue disorders are the top three diagnostic categories for hospitalizations after deployment.[75]

Several risk factors have been identified for musculoskeletal injuries. Lincoln and colleagues analyzed records of over 15,000 active-duty personnel hospitalized for common musculoskeletal conditions between the years 1989–1996 and identified the following risk factors for disability among US Army personnel: low pay, high age, smoking, previous musculoskeletal injuries, work stress, heavier physical demands, and low job satisfaction. Behavioral, psychosocial, and occupational interventions were suggested to modify such factors.[4] Female gender has been identified as a risk factor for musculoskeletal injuries and discharges in several studies[6, 76, 77]; but, Bell and colleagues reported no gender differences in injury rates when adjusting for fitness level and body composition, suggesting the importance of achieving a high fitness level in reducing injury risk.[78] Several studies have evaluated

musculoskeletal risk factors and reported low fitness level, previous injury, too high or too low flexibility, and high running mileage as risk factors of common musculoskeletal injuries.[2, 8-13]

Because soldiers with low fitness levels suffer musculoskeletal injuries more frequently, several researchers have attempted to modify physical training or to implement screening procedures and physical readiness training programs for those who did not meet fitness requirements.[79-82] Knapik and colleagues evaluated the effects of physical readiness training, which emphasized less running, more exercise variations, and integration of various training elements to reduce injuries and increase functional fitness, on musculoskeletal injury rates and the APFT outcomes during the 9-week Basic Combat Training phase. It was reported that this training reduced overuse injuries, did not change the rate of traumatic injuries, and improved success rates on the fitness tests.[79] While it is important to continue improving such injury prevention programs and provide epidemiological data, it is also essential to understand how such programs induce physiological adaptations in the musculoskeletal system.

2.2 THE PHYSIOLOGIC BASIS OF FUNCTIONAL JOINT STABILITY

2.2.1 Overview

A general medical dictionary defines stability as the state of remaining unchanged, even in the presence of forces that would normally change the state or condition.[83] With respect to the human body, stability is described as the property of returning to an initial state upon disruption.[41] Based on the above definitions, joint stability is defined as the state of a joint remaining or promptly returning to proper alignment through an equalization of forces.[44]

Functional joint stability is defined as possessing adequate joint stability to perform functional activity and results from the interaction between static and dynamic components.[18, 19] The static or mechanical components of joint stability are the ligaments, joint capsule, cartilage, friction, bony geometry within the articulation, and passive musculotendinous structures.[44]

The dynamic components of joint stability arise from feedforward and feedback neuromotor control over the skeletal muscles crossing the joint.[44] Feedback controls refer to the stimulation of a corrective response within the corresponding system after sensory detection and feedforward controls refer to anticipatory actions occurring before the sensory detection of a homeostatic disruption.[41, 44] As separate entities, neither the mechanical nor dynamic restraints are sufficient to result in FJS; a mechanical-dynamic restraint interaction is required to achieve a stable joint. This interaction between the static and dynamic components of functional stability is mediated by the sensorimotor system. The sensorimotor system encompasses all of the sensory, motor, and central integration and processing components of the CNS involved in maintaining FJS.[20]

2.2.2 Static Component of Functional Joint Stability

Mechanical or static stability is provided by several anatomical structures including ligaments, the joint capsule, and cartilage as well as bony geometry and friction. The primary role of these structures is mechanical, as they are used for stabilizing and guiding skeletal segments.[84] This requires all of the elements to possess complex biomechanical characteristics as primary and secondary restraints.[84] For example, the ACL acts as a primary restraint to proximal anterior tibial translation and as a secondary restraint to knee valgus and internal rotation. The loss of or damage to the ACL results in increased anterior tibial translation, valgus, and internal

rotation.[85-89] The joint capsule provides mechanical stability much like a ligament. For example, the deep medial collateral ligament and the posteromedial capsule of the knee provide the joint stability against valgus and internal rotational torques.[90] Cartilage such as the menisci of the knee are reported to help joint stability by deepening joint congruency, wedging to prevent anterior translation, and increasing the bony contact area.[91, 92] The bony geometry such as the posterior slope of the tibial plateau is reported to play an important role in preventing anterior-posterior translation and adding stability of the tibia.[93, 94] Passive musculotendinous structures provide mechanical joint stability as well.[95] The passive musculotendinous structures refer to the viscoelastic contributions from the non-contractile elements.[40, 96]

2.2.3 Sensory Contributions in Functional Joint Stability: Proprioception

Static structures including the capsule, ligaments, muscles, and tendons play not only a mechanical role but also a sensory role. There are different types of afferent sensory organs (mechanoreceptors) found in the various knee joint structures. For the purpose of this study, the mechanoreceptors pertaining to the knee joint are described further. Ruffini receptor endings, Pacinian corpuscles, Golgi tendon organ-like endings, and free nerve endings are found in the cruciate and collateral ligaments, menisci, and joint capsule.[32, 97-101] Muscle spindles and GTOs are found in the intrinsic muscles and musculotendinous junctions, respectively.[102]

Ruffini endings have a low threshold to mechanical stress and are slow adapting endings. Therefore, the signals from the Ruffini endings contain information about the static joint position, intraarticular pressure, and amplitude and velocity of joint rotations.[30] Additionally, the Ruffini endings are active throughout the range of motion and provide information concerning joint angles and limb movements in the midrange of motion.[103] Pacinian corpuscles demonstrate

a low threshold to mechanical stress, show rapid adaptations, and are very sensitive to acceleration and deceleration; therefore, these corpuscles behave as pure dynamic mechanoreceptors.[31] Golgi tendon organ-like endings demonstrate slow adaptation and high thresholds to mechanical stimuli. Because of this high threshold, these receptors are active towards the end range of joint motion.[32] Free nerve endings are silent during normal conditions but become active when the articular tissue is subjected to damaging mechanical deformations such as ligamentous sprains.[33] Muscle spindles are oriented in parallel with the skeletal muscle fibers. This arrangement allow these receptors to encode the event of muscle stretch as well as the rate of passive elongation.[34] In contrast, GTOs are aligned in series within the musculotendinous junctions, encoding the stretch on the tendon generated by the total force of a given muscle during contraction.[34] Muscle spindles and GTOs play an important role in regulating muscle tone and joint stiffness, especially during dynamic tasks.[35, 36] The regulation of muscle tone and joint stiffness is discussed in detail in a later section.

Collectively, proprioception is defined as the afferent information arising from the internal peripheral areas of the body that contributes to postural control, joint stability, and several conscious sensations.[44] Proprioception has several submodalities: joint position sense (the appreciation and interpretation of information concerning joint position and orientation in space), active and passive kinesthesia (the ability to appreciate and interpret joint motions), and the sense of heaviness (the ability to appreciate and interpret force applied to or generated within a joint).[44] Proprioceptive information from afferent sensory organs (mechanoreceptors) is transmitted to the CNS where it is processed and integrated with other signals to regulate neuromuscular control and properly maintain joint stability.[20] Therefore, proprioception plays a vital role in maintenance of joint stability of the knee via the sensorimotor system. Any processes

that affect proprioception or processing of afferent information can have a significant impact on FJS.[20, 40]

2.2.4 Central Processing and Integration

Proprioceptive information arising from articular mechanoreceptors travels to two separate destinations: the gray matter of the spinal cord to elicit local segment cord reflexes and the higher levels of the nervous system including the brain stem, cerebellum, and the cerebral cortex.[102] There are several ascending pathways to the supraspinal centers, specifically either of the dorsal lateral tracts or the spinocerebellar tracts.[44, 104] At each level, the sensory information is processed and integrated to elicit motor commands.

At the spinal cord level, peripheral sensory information elicit the direct reflexes (monosynaptic reflex path) and/or reaches the interneurons (polysynaptic reflex path) to involve excitation of alpha- and gamma-motor neurons and assist in producing elementary patterns of motor coordination (rhythmic and central pattern generators) with other descending commands from high centers.[44, 105, 106]

The brain stem integrates proprioceptive signals with afferent information from vestibular and visual centers and other somatosensory input to directly control automatic tasks. The integration of proprioceptive sensory information and motor control, along with vestibular and visual information, are described in detail.[107-109] Additionally, the brain stem indirectly relays information between the cortex and spinal cord, and modifies descending motor commands.[20] The dorsal spinocerebellar tracts provide proprioception data regarding position and rate of change of joint movement and the ventral spinocerebellar tracts provide nearly instantaneous information concerning the actual sequence of motor signals that have arrived at the anterior

horn cell level within the spinal cord.[110] The cerebellum sends and receives input from the cerebral cortex. Therefore, the cerebellum compares the intentions of the cerebral motor control system and the motor signals at the anterior horn cells and regulates the intensity and sequence of motor actions of agonist and antagonist muscle groups.[110]

The cortex receives and perceives sensory information (conscious appreciation) and controls fine coordinated complex movement patterns.[111] Motor signals are transmitted directly from the cortex to the spinal cord through the corticospinal tract and indirectly through multiple accessory pathways that involve the brain stem and cerebellum.[102] Therefore, the cerebral cortex can influence the alpha- and gamma-motor neurons as well as complex movement patterns and plays an important role in joint stability.[44]

2.2.5 Dynamic Components of Functional Joint Stability: Neuromuscular Control

The dynamic components of joint stability arise from feedforward and feedback neuromotor control over the skeletal muscles crossing the joint.[44] Neuromuscular control is defined as the unconscious activation of dynamic restraints occurring in preparation for, and in response to, joint motion and loading for the purpose of maintaining and restoring FJS.[44] The dynamic components of FJS depend on information derived from sensory afferents about joint movement, position, and forces; the regulation of muscle stiffness via the gamma-muscle spindle system is crucial in achieving FJS.

Humans use a combination of feedforward and feedback mechanisms. Feedback control uses information about the current state of a person and the external environment to modify muscle activity.[35] Feedforward control does not require peripheral receptors and modifies muscle activity by anticipating the external environment.[35] In walking animals, feedback control

integrates information from many different pathways including the eyes, the vestibular system, proprioceptors, and cutaneous receptors.[112-115] There are two fundamentally different ways that the CNS uses sensory feedback. First, afferent feedback, which is a part of normal movement, is used as an integrated part of motor commands in the activation of muscles. This feedback is anticipated by the CNS and built in to the motor programs controlling movement.[45] Second, a reflexive response is generated when there is an unpredicted disturbance of movement or an unexpected change in the sensory feedback. These reflexes constitute error signals, which aim to correct the on-going movements and avoid falling. Although the reflex signals are not sufficient to correct the movement, the error signals inform the higher structures of the brain about the disturbance and help the brain to adjust the motor programs to regulate joint stiffness.[45, 46]

Joint stiffness involves all structures in and around the joint. As the main contributor to joint stiffness, muscle stiffness is defined as the ratio of change in force to change in length and consists of two components: an intrinsic component and a reflex-mediated component.[37, 116, 117] The intrinsic component depends on the viscoelastic properties of the muscle and the number of actin-myosin bonds while the reflex-mediated component depends on the excitability of the alpha motor neuron pool.[38, 39, 118] The gamma-muscle spindle system is influenced by mechanoreceptors of ligaments and other joint structures and integrates with descending command and reflex input. Collectively, all of these influences alter the sensitivity of the muscle spindles; thus, the final afferent signals arising from the muscle spindles can considered a function of both the preceding influential activity and all afferent proprioceptive information. This system can change the sensitivity and threshold of the alpha-motor neuron pools, regulating the amount of intrinsic muscle stiffness.[38, 39, 41, 118, 119] This control mechanism is known as the "final common input" hypothesis.[119] A lower recruitment threshold enhances the number of

muscle fibers activated per given input from the motor drive; therefore, recruitment threshold plays a major role in functional knee joint stability.[120] Increased muscle stiffness has two advantages: increased resistance against sudden joint displacement and increased time to transmit loads to the muscle spindles, making quick initiation of reflexive activity.[42, 43, 121] As stated before, the proprioceptive information from these structures provides the CNS with information of unusual events (joint perturbation) as a part of the feedback control system and assists in modifying the dynamic components to achieve maximal FJS.[122] Acute adaptations of muscle activation patterns to minimize co-contraction are reported in a few trials and play an important role in long-term skill acquisition.[122-127]

Since the reflex signals are insufficient to correct the movement or to prevent injuries in terms of muscle timing and amplitude, humans use feedforward control as well.[128, 129] Through feedforward control, muscles surrounding a joint activate prior to foot contact or perturbation to achieve joint stability. Feedforward control has two ways of achieving joint stability: short-range stiffness and muscle pre-activation. First, activated muscles provide resistance against sudden stretch or joint perturbation as explained in the previous section. Since muscles are already active at the time of perturbation, the time to reach peak force is very short (less than 50ms) thereby providing substantial response to the perturbation.[47, 48] This fast production of force with minimal joint displacement is called short-range stiffness and is considered to be the first line of defense.[49, 50, 130] Second, muscle pre-activation (onset time and amplitude) is modified in order to prepare the musculoskeletal system to withstand the external forces according to the external environment or the conditions of the playing surface. There are several ways to improve the motor neuron drive: increased firing frequency, increased motor unit recruitment, increased

motor unit synchronization, and decreased thresholds, all of which result in changes in EMG readings.[131]

Significant CNS motor learning (central pattern generation) takes place acutely and chronically through both feedback and feedforward controls to regulate joint stiffness.[105, 106] The role of proprioception is not only for the afferent joint information, but for motor skill acquisitions and motor coordination.[27, 28, 132] One important aspect of the dynamic component is the plasticity of the CNS to adapt and regulate the joint stiffness by altering muscle activation timing and amplitude as well as joint position and body posture. For example, through repetitive trials (practice trials) during a drop-landing task with the eyes closed, the EMG onset and amplitude become similar to the eyes open conditions.[133] When landing on an uneven/slippery surface or acquiring a complex coordination task for the first time, general co-contraction strategies are used to stabilize the joint.[134-138] These observations support the importance of interactions between the mechanical and dynamic components and all of the sensory, motor, and central integration and processing components of the CNS.

2.3 CONTRIBUTORS OF FUNCTIONAL KNEE JOINT STABILITY

2.3.1 Overview

The previous section describes the physiologic basis of the static and dynamic components of FJS and how these components are mediated by the sensorimotor system, which encompasses all of the sensory, motor, and central integration and processing components of the CNS, to achieve the FJS. Unfortunately, the interaction between the static and dynamic

components and the sensorimotor system is very complex; there is no single variable that can be measured or used to define as FJS. Additionally, most assessment techniques currently utilized during *in vivo* research evaluate the integrity and function of sensorimotor components by measuring variables along the afferent or efferent pathways, the final outcome of skeletal muscle activation, or a combination of these.[139] This section focuses on specific variables that play an important role in joint stability *in vivo* and are hypothesized as contributors to functional knee joint stability. Two important contributors are discussed: the accuracy of conscious proprioception and the regulation of joint stiffness.

In order to support the importance of these contributors to functional knee joint stability, ACL injury studies are reviewed and used as a model to understand the effects of each contributor separately. There are a few reasons for reviewing ACL literature. First, it is one of the most studied structures in the lower extremity. ACL research areas are diverse, encompassing topics from basic science to applied human movement science to epidemiological based studies. Second, the mechanoreceptors from the ACL provide proprioceptive information and influence muscle spindles to help regulate muscle stiffness via the gamma-motor neuron system, as previously mentioned. ACL studies evaluating knee function after ACL injury provide valuable evidence about the role of proprioceptive information in the integrity of functional knee joint stability and various adaptations. Third, it is well recognized that non-contact ACL injuries are prevalent among active people and that females have higher injury rates compared to their male counterparts.[140-146] This discrepancy brings much attention to the evaluation of modifiable risk factors: neuromuscular and biomechanical variables. Because many variables have been identified as risk factors of female ACL injury in the past, these risk factors are briefly

mentioned. However, this dissertation focuses on more general variables that would contribute the functional knee joint stability.

2.3.2 Accuracy of Conscious Proprioception as a Contributor of Functional Joint Stability

Conscious proprioception is divided into four submodalities: 1) joint position sense (JPS) – the ability to reproduce the same joint position actively or passively, 2) kinesthesia which is measured by threshold to detect passive motion (TTDPM) – the ability to detect the initiation of passive joint movement, 3) velocity sense (VS) – the ability to reproduce the same velocity, and 4) force sense (FS) – the ability to reproduce the same force. Previously, the majority of knee conscious proprioception studies have included only JPS and TTDPM.[147-153] Joint position sense is influenced by slow adapting mechanoreceptors.[154, 155] Threshold to detect passive motion is influenced by muscle spindles, and skin and articular mechanoreceptors.[156] The muscle spindle signals changes in length of the muscle fascicles, which are suggested to play a main role in TTDPM.[157] The velocity of passive movement during TTDPM is typically very slow and because movement is perceived prior to the direction of the movement, it is argued that only when an awareness of both movement and direction is required can these tests be regarded as specific for proprioceptive mechanisms.[158]

Several studies have evaluated VS in the upper extremity, but few have studied it in the lower extremity.[159-163] Velocity sense is assessed by either velocity replication (the ability to reproduce a reference velocity) or velocity discrimination (the ability to differentiate slower or faster velocity relative to a reference velocity). Velocity replication has demonstrated reliability similar to JPS and TTDPM tests.[163] Velocity sense is mostly influenced by muscle spindles and

cutaneous information similar to active JPS, but it is associated with a complex mixture of different cues such as timing, location, distance, and velocity.[162] Force sense is measured by assessing the ability to reproduce a reference torque and is thought to have two sources: the sense of tension generated by afferent feedback from the muscle and the sense of effort generated centrally.[164] Force sense reproduction, which provides a measure of the integrity of muscle spindles and tendon organs per given effort, is reported to have good reliability in the shoulder literature.[165]

Previously, researchers have reported proprioceptive deficits after ACL injury and that these deficits persist even after reconstructive surgery.[147-151] Similarly, people with chronic ankle instability exhibit proprioception deficits.[166-168] Force sense has a significant correlation with joint stiffness in subjects with chronic ankle stability.[169] A few studies have compared proprioception in the knee between genders and it has been reported that females have less ability to detect TTDPM toward extension compared to their male counterparts.[170, 171] Based on these studies, it has been suggested that proprioception plays an important role in the maintenance of joint stability. In addition, others have reported that subjects with poor proprioception and joint stability exhibit single-leg balance and strength deficits.[172-178] This observation can be explained by the role of proprioceptive feedback in directly influencing peripheral and central motor control.[179, 180] Collectively, several studies have demonstrated that enhanced conscious proprioception is associated with higher functional tests and patient satisfaction scores in individuals with ACL-deficiency or ACL-reconstruction.[149, 178, 181] Additionally, ACL-deficient individuals with no functional limitations have scored TTDPM and JPS values similar to those in the non-injured group.[182]

A recent prospective biomechanical-epidemiology study reported that collegiate athletes with decreased ability in trunk active JPS have a three-fold increase in the odds ratio of knee injury.[183] Similarly, proprioception deficits have been reported to be a risk factor for ankle injuries.[184, 185] Payne and colleagues evaluated ankle proprioception, strength, and flexibility in 42 college basketball players and reported that proprioception variables, but not strength or flexibility, predicted ankle injury the most.[184] A study by Willems and colleagues assessed joint position sense, physical characteristics, lower leg alignment, and muscle reaction time for 159 females; poor passive joint position sense was identified as a risk factor while muscle reaction time, physical characteristics, and strength were not.[185]

Previous studies on conscious proprioception have raised a question as to whether conscious proprioception acuity is genetic or acquired; it is generally agreed that the latter has more supportive evidence.[186] There have been a few studies that have evaluated the effects of physical training on conscious proprioception and they are discussed in a later section.[55, 187, 188] The studies detailed above highlight the importance of conscious proprioception and support conscious proprioception as a contributor to functional knee joint stability.

2.3.3 Regulation of Joint Stiffness as a Contributor of Functional Joint Stability

The basic concept of joint stiffness is based on Hooke's Law of elasticity from the field of physics. Mathematically, it is defined as $F = kx$, where (x) is the distance the spring is elongated, (F) is the restoring force exerted by the spring, and (k) is the spring constant or force constant of the spring (Figure 6).

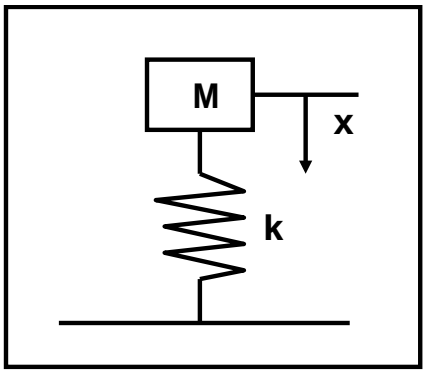


Figure 6. A spring-mass model

Taken from this concept, the human body during running and hopping can be modeled as a spring-mass system.[189] This simple model is used to study the vertical stiffness of all lower extremity joints combined as k(vertical) = Fmax / Δ y, where (k(vertical)) is the vertical stiffness, (Fmax) is the peak vertical ground reaction force, and (Δy) is the maximum vertical displacement of the center of mass of a subject. In order to evaluate the stiffness of each ankle, knee, and hip joint, the net joint moment and angular joint position are used instead of the vertical ground reaction force and the vertical displacement of the center of mass, respectively.[24, 190] Therefore, the joint stiffness is determined as k(joint) = ΔM(joint) / Δ Θ(joint), where (k(joint)) is the joint stiffness, (ΔM(joint)) is the change in net joint moment, and (Δ Θ(joint)) is the change in angular joint displacement. Stiffness is calculated as the slope of the line on the moment–angle curve as drawn from the point of maximum knee flexion moment to the point of maximum knee extension moment occurring between initial contact and the maximum knee flexion angle (Figure 7).[191]

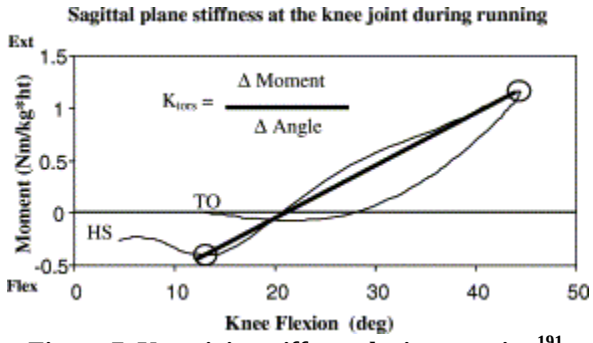


Figure 7. Knee joint stiffness during running[191]

Other researchers have further separated the joint stiffness into musculotendinous, tendinous, and contractile stiffness.[192, 193] However, for the purpose of this dissertation, total joint stiffness is used throughout the paper. Joint stiffness can be influenced by several neuromuscular and biomechanical factors: muscle activation pattern, muscle strength, and lower extremity kinematics during ground contact.

Greater muscle activation of the agonist muscle or co-contraction of the antagonist muscles can increase joint stiffness prior to or at foot contact.[194-196] For example, during a drop-landing task from a tall box, a person has an earlier onset of quadriceps activation and higher amplitude of EMG prior to foot contact as compared to a small box drop-landing.[26] The muscle reflexes through the gamma-motor neuron system regulate joint stiffness by altering the threshold of the alpha-motor neuron; the details of this interaction were discussed in the previous section.[36, 197] Anticipatory muscle activations prevent joint collapse as well as produce an efficient push-off during a cyclic movement.[195, 196] As previously stated, muscle stiffness has two components: an intrinsic component and a reflex-mediated component.[37, 116, 117] Due to joint geometry, length-tension relationship, and moment arm length, joint angle has been shown to influence joint stiffness.[190, 198] In addition, muscle strength can increase the joint stiffness per given muscle activation. In fact, a study by Wilson and colleagues evaluated the relationship between musculotendinous stiffness and eccentric, concentric, and isometric performance, and

reported a high correlation between stiffness and maximum isometric force and RFD.[199] The regulation of joint stiffness is one of the fundamental roles of sensorimotor system from a physiological point of view; therefore, it is a major contributor to functional knee joint stability.

In gender comparison studies, female athletes exhibit less strength, even after normalization to body mass, in almost all studies.[200-203] Female athletes also exhibit less leg and musculotendinous stiffness, suggesting that fundamental morphological differences exist between genders.[204-209] In order to compensate for less joint stiffness and strength, females demonstrate greater muscle activation to counteract and absorb landing impact. Because muscle activation can largely increase leg stiffness to withstand perturbation forces as the first line of defense, greater knee joint stiffness is achieved by co-contraction of the muscles that surround the knee or by selective activation of specific muscle groups prior to and during impact.[210-215] More specific to gender differences, females have demonstrated more quadriceps and less hamstrings activation than their male counterparts.[68, 216] This 'quadriceps dominant' activation pattern can stabilize the joint; however, it can increase anterior shear forces and translation which predispose females to a higher risk of ACL injuries.[68, 216] Large skeletal muscles require some time to develop adequate force and may develop this force too late after impact to withstand forces; therefore, co-contraction ratio prior to impact has been studied.[217, 218]

Joint position plays an important role in regulation of functional knee joint stability. First, joint stiffness is influenced by joint position due to its bony geometry, moment arm, and force-length relationship.[190, 198] Second, certain joint positions are associated with injury mechanisms. Video analyses of non-contact ACL injury suggest that the knee flexion angle is typically 30 degrees or less when ACL injury occurs.[219, 220] Additionally, the line of action for the quadriceps is directed anteriorly at knee flexion angles of 30 degrees or less while the line of action for the

hamstrings is almost vertical.[221] Researchers claim that the quadriceps alone can tear the ACL; therefore, the knee flexion angle combined with anterior shear forces and quadriceps knee moments are identified as potential risk factors of female non-contact ACL injury.[222, 223]

Computer simulation studies have demonstrated that secondary rotations (valgus/varus and internal/external rotations of tibia) are also responsible for the majority of non-contact ACL injuries.[224, 225] Both video analysis and computer simulation of non-contact ACL injuries support that valgus landing is a common mechanism of non-contact ACL injury.[219, 224, 225] Several authors have reported that females land with less knee flexion at foot contact compared with their male counterparts.[200, 216, 226] It is also commonly reported that female athletes demonstrate greater knee valgus angles and moments during dynamic movements compared to their male counterparts.[216, 223, 227, 228]

Several studies have reported that hip and trunk position as well as strength can influence knee angles.[229-231] Willson and colleagues evaluated trunk, hip, and knee strength and reported the relationship between straighter lower extremity alignment (less knee valgus and more hip external rotation) during a single-leg squat.[230] Similarly, Jacobs and colleagues reported that decreased hip abductor strength is associated with greater knee valgus angles during a drop landing task.[229] Blackburn and Padua reported that greater trunk flexion during a drop landing is coupled with greater hip flexion and knee flexion; this demonstrates the importance of the trunk position for proper lower extremity alignment.[231]

A prospective biomechanical-epidemiological study demonstrated that valgus moments and valgus angles, when combined, have the highest predictive value for ACL injury among all other biomechanical variables.[232] Later studies by Zazulak and colleagues also identified deficits in neuromuscular control of the trunk and poor active proprioception scores as risk factors of

knee injury.[183, 233] Functional knee joint stability is not only associated with biomechanics and neuromuscular control of the knee joint, but with other joints as well. Intervention programs should target for the neuromuscular and proprioception improvements over the whole body.

2.4 EFFECTS OF INTERVENTION PROGRAMS ON PHYSICAL FITNESS AND INJURY PREVENTION

2.4.1 Overview

An epidemiological study design is one of the simplest ways to evaluate the effects of intervention programs on functional knee joint stability. As mentioned previously, the US Army evaluated the effects of an intervention program with less running, more exercise variations, and integration of various training elements and reported a reduction in overuse injuries.[79] In ACL injury prevention research, there are more prospective intervention studies with various modes of exercises. Three studies have included unstable surface training with balance exercises and reported mixed results on the number of ACL injuries.[234-236] While intense and challenging balance exercises may help reduce non-contact ACL injuries, it is not conclusive that balance exercises alone can reduce the rate of ACL injuries.[235] Resistance training may help to reduce the number of injuries; however, only a few studies on resistance training are available and these studies do not specifically examine ACL injury reduction.[237, 238] Several studies have used prevention programs that consist of various types of exercises: plyometric, balance, and agility exercises. A subsequent reduction in ACL injury rate was reported.[239-243]

Others studies have investigated biomechanical and neuromuscular characteristics and how these parameters are changed after the implementation of a prevention program.[56-63, 65-70, 244-248] By examining the identified potential risk factors of ACL injuries in female athletes, biomechanical and neuromuscular characteristics are used to evaluate the effectiveness of prevention programs.

2.4.2 Effects of Strength Training

In general, strength training is associated with neural and muscular adaptations which improve strength. Neural adaptations include increased activation of the agonist muscle, spinal cord connections, and coordination, while muscular adaptations include muscular hypertrophy and an increase in specific tension.[51-53] Since muscle morphological adaptations take 30-60 days to produce significant changes, strength gains after 4-6 weeks of training are mainly due to neural adaptations.[249-251] From a FJS point of view, increased strength is beneficial for both feedback and feedforward control. Increased muscle strength means greater stiffness per given muscle activation level; therefore, it has more potential to protect a joint from joint disrupting forces. It is suggested that strength training can improve mechanical output by increasing efficiency of the central command.[54]

Strength training has been shown to improve proprioception.[55] Thompson and colleagues evaluated the effects of strength training on elderly women and reported improved knee proprioception, as measured by TTDPM and active JPS.[55] However, there are few studies that have evaluated the effects of strength training on proprioception.

2.4.3 Effects of Plyometric Training

Similarly, plyometric training is associated with neural and musculotendinous adaptations. Most plyometric exercises are designed to train a specific movement pattern: a combination of eccentric and concentric muscle function, called the stretch-shortening cycle (SSC).[252, 253] The storage and utilization of elastic energy by the tendon are proposed as a major mechanism for the enhancement of concentric work (last phase of the SSC).[193, 254, 255] Plyometric adaptations include an increase in vertical jump height, rate of force development, and area of fast twitch fibers, coupled with a decrease in metabolic demand.[256, 257] From an FJS point of view, these adaptations are advantageous for feedback control as a body quickly reacts to joint disrupting forces to prevent or minimize future injuries. The other advantage is training specific motor learning.

The influence of plyometric exercises on biomechanical and neuromuscular characteristics is widely studied. Plyometric exercises are effective in reducing vertical GRFs, improving knee extensor and flexor strength, improving the knee flexor/extensor strength ratio, and increasing eccentric leg stiffness.[66-70] These results suggest that plyometric exercises can improve the ability to utilize musculo-tendon structures to absorb energy effectively and minimize GRFs. Other benefits of plyometrics include a reduction in knee valgus moment, an increased co-contraction of hip abduction and adduction muscles in the pre-landing phase, and an improvement in balance.[57, 58, 68, 244]

2.4.4 Effects of Neuromuscular Training

Several studies have analyzed biomechanical and neuromuscular characteristics after neuromuscular training (typically a combination of plyometric, resistance, balance, perturbation, and agility training) and reported increases in knee extensor and ankle plantarflexor strength as well as improvements in single-leg balance, the rate of force development, and agility performance.[245-248] In addition, the finding of increased pre-activation of the hip abductors supports the idea that these exercises can influence the hip musculature.[246] Prospective intervention studies support the rationale of using neuromuscular training to reduce ACL injuries in female athletes.[239-243]

2.4.5 Effects of Unstable Surface Training

Compared with strength and plyometric training, unstable surface training is not widely studied for athletic performance.[258] Previous studies on unstable surface training have evaluated its impact on postural stability and proprioception of the ankle.[259-262] It is clear that the purpose of such training programs is to improve conscious proprioceptive appreciation and overall postural stability. As discussed in the previous sections, afferent sensory information, neuromuscular control, and central processing work together for comprehensive sensorimotor control to achieve FJS, and these components can be improved through specific exercises. From this perspective, these types of exercises must be incorporated into any type of injury prevention training program.

Improvements in postural stability, knee strength, and landing mechanics (less valgus) are reported after the incorporation of balance exercises.[56-58] Perturbation exercises - aggressive

modes of unstable surface training - might be more potent in injury prevention by improving RFD, leg stiffness, and muscle activation of both knee flexor and extensor muscles.[59-63] Bruhn and colleagues compared the effects of unstable surface training and strength training on jump performance and reported improved squat-jump performance following strength training and improved drop-jump performance following unstable surface training. Both trainings improved RFD.[59] Unstable surface training can influence reflexes as high muscle activation is observed during the drop-jump; enhanced reflexes are essential in reactive performance.[263] This suggests that unstable surface training can enhance the afferent pathways.[59]

2.5 DESIGNING PERIODIZED TRAINING PROGRAM

2.5.1 Concepts of Traditional (Linear) Periodization Training

The concept of linear periodization training is largely based on the physiological adaptation to stress and is known as the general adaptation syndrome (GAS). The general adaptation syndrome was originally described by the Canadian biologist, Selye, in 1956.[264] There are three stages in which the human body reacts to stress: the alarm phase, the resistance phase, and the exhaustion phase.[265] The alarm phase is experienced as muscle soreness, stiffness, and a temporary drop in performance develop. The resistance phase is experienced as the body adapts to the stimulus and returns to more normal function or even greater compensation (supercompensation). The exhaustion phase is experienced as a decrease in performance. Well designed conditioning programs should avoid this exhaustion phase. Overtraining is commonly reported in both civilian and military studies; however, the mechanisms and nature of

overtraining remain largely unknown.[266-269] In order to avoid such a devastating phase, many coaches include training cycles, typically based on the annual plan, called a macrocycle. The macrocycle is further subdivided into the monthly plan (mesocycle) and the weekly plan (microcycle).[270] Anecdotal evidence from coaches around the world makes the concept of periodization very popular and there are numerous short-term studies that show the positive effects of periodized training over conventional progressive training.[271-273] However, there have been very few long-term studies to substantiate the claim. The concept of periodization is a part of framework for understanding the training process leading to elite performance.[274]

The periodization for strength/power training and development consists of preparatory, hypertrophy/endurance, strength/power, and competition phases as well as a transition period between sequential phases.[265] The preparatory phase establishes a base level of conditioning through low intensity and high volume exercises. It is also the phase in which fundamental lifting techniques are taught individually. The focus of the hypertrophy/endurance phase is to build lean muscle mass and increase muscular endurance in order to prepare the body for the next phase through low to moderate intensity and high volume exercises. The strength/power phase builds muscular strength and explosive power through medium-high intensity and low-medium volume, preparing the body for the next and final phase. In the competition phase, the focus is shifted to maintain strength/power and further improve strength/power without building any fatigue. The focus of the transition period between sequential phases is to ensure proper recovery from the previous phase and readiness for the next phase.

The periodization for distance running consists of foundation/injury prevention, early quality, transition quality, and final quality phases.[275] According to this model, the initial phase is designed to build basic physical fitness with easy runs, strengthening routines, and stretching.

The early quality phase introduces faster speed and longer stride runs with a long recovery. The next phase involves more intense and event-specific training. The last phase is designed for peak performance by maintaining (tapering) the current condition and preparing specific race situations.

These two linear periodization programs (strength/power and endurance) have a common goal and common building cycles specific to sports and their requirements (Figure 8). Each sport can be divided into off-season, pre-season, and in-season, with the intensity, duration, and volume of training varied based on the season. However, this seasonal periodization cycle is not realistic for soldiers who must be ready for tactical missions at all times. Their schedules are based on various factors: national training, unit training, block-leave, policy changes, deployment, re-deployment, and holidays. In addition, soldiers must prepare their bodies for agility, quickness, and strength/power as well as endurance. The traditional periodization of strength/power or endurance alone is too specific to cover all aspects of physical fitness. In order to meet such physical demands, a new concept of nonlinear periodization should be used to train soldiers.

Annual/Bi-annual Plan	Resistance Training Periodization	Endurance Training Periodization
	Phase I: Preparatory	Phase I: Foundation/Injury Prevention
	Phase II: Hypertrophy/Endurance	Phase II: Early Quality Run
	Phase III: Strength/Power	Phase III: Transitional Quality Run
	Phase IV: Competition	Phase IV: Final Quality Run
	Transition Between Each Phase	Transition Between Each Phase

Figure 8. Linear Periodization Model for Resistance and Endurance Sports

2.5.2 Concepts of Nonlinear Periodization

Nonlinear periodization theory and concept was introduced by Poliquin in 1988.[276] This nonlinear periodization program for a football team was 8-weeks long and each session had different repetitions, intensities, volumes, and speeds of contraction rather than slow gradual increases in all of these resistance training parameters (repetitions, intensities, volumes, speeds of contraction, and rest). The program began with the general conditioning phase followed by slower strength, faster strength, and explosive phases, with each phase lasting only 2-weeks long. A few studies have evaluated the effectiveness of various periodization programs and compared the differences between the traditional periodization and nonlinear periodization programs. Mixed results are reported.[277-279] Baker and colleagues compared the effects of 12 weeks of a linear periodization, a nonlinear periodization, and a nonperiodized control model on maximum squat and bench press, vertical jump, and lean body mass.[277] The nonlinear periodization with a 2-week undulating cycle was used in this study; no significant advantages over the linear periodization or the nonperiodized programs were found. A similar study by Buford and colleagues reported no differences on bench press, leg press, body fat percentage, or limb circumference between linear and nonlinear periodization programs.[279] Rhea and colleagues used a nonlinear periodization model which undulated lifting repetitions and volumes and reported favorable results on bench press and leg press after 12 weeks, as compared to the linear periodization model.[278]

There have been a few studies exploring the relationship between nonlinear periodization and endurance training. Generally, coaches vary workout intensity and duration within each training phase, thereby creating a small scale nonlinear periodization. For example, in the early quality training phase, the goal is to introduce faster speed. Weekly workouts include interval

runs (200m and 400m at current mile race pace with plenty of recovery time between runs), strides (20-40s runs at about mile race pace), and resistance training mixed daily or weekly, resulting in a hybrid nonlinear periodization model.[71] Coaches for endurance sports have used the energy system and mechanical power (or running speed) to establish various types of exercise intensities.[71, 270]

Several studies have included both strength/power and endurance workouts (concurrent training) within weekly workouts.[280-287] Physiological adaptations after concurrent training are inconclusive; however, it is generally accepted that concurrent training can moderately improve both strength and endurance athletic performance. Kraemer and colleagues compared a concurrent training program to various types of resistance training programs and an aerobic-only program. Better push-up and sit-up performance was seen after the concurrent training while 2-mile run-time was better after the aerobic-only training.[288, 289] Plyometric training may be associated with the improved running economy.[290] Typical weekly workouts include 2-3 strength/power workouts and 2-3 endurance workouts, alternating between the strength/power day and the endurance day. This training concept is similar to the daily undulating nonlinear periodization model, in which the training volume, intensity, duration, and modes are altered every single day. For example, on endurance days, 1-2 endurance days cover higher intensity aerobic workouts (200m-1mile interval and sprint repetition workouts) while other endurance days could cover long duration slow aerobic workouts (distance running). The endurance day is followed by resistance training with two different training targets (strength/hypertrophy with 10-15 repetitions/set and power with 5 repetitions/set).[280] This concept is well suitable for soldiers who must prepare for various tasks.

2.6 METHODOLOGY CONSIDERATIONS

2.6.1 Overview

For the purpose and nature of this study, it is important to know the consistency of the intersession (test-retest) reliability and precision in healthy individuals to set the norm values for all tests. Reliability is defined as the degree of consistency with which an instrument or rater measures a variable.[291] Precision is defined as a measure made so as to vary minimally from a set standard.[292] Both reliability (intraclass correlation coefficient (ICC)) and precision (standard error of measurement (SEM)) of all testing variables were evaluated prior to this study. It is suggested that an ICC value of 0.8 is necessary to be considered of good reliability and clinically significant.[291]

2.6.2 Assessment of Knee Conscious Proprioception

A previous reliability study reported an ICC of 0.80 and precision of 2.3 degrees for knee JPS.[293] One study reported the test-retest reliability of the knee TTDPM (r = 0.92), while the ICC and precision were not reported.[294] The ICC and precision for velocity sense have been reported to be 0.41-0.85 and 0.77-5.31 degrees/sec, respectively.[163] Better ICC and SEM values were reported for slower velocities than faster velocities. Because there are few studies of force sense tests on the knee, the reliability and precision of these tests are not available. However, the reliability and precision of force sense at the ankle joint has been evaluated and reported ICC and SEM values of 0.84-0.89 and 0.97-2.42N, respectively.[295]

Prior to this dissertation, the intrasession and intersession reliability and precision of proprioception tests were evaluated in the Neuromuscular Research Laboratory. Ten healthy individuals (5 males, 5 females; Age: 24.1±2.1yrs; Ht: 177.0±13.0cm; Wt: 70.7±14.2kg) participate in this pilot study. All testing was performed using isokinetic dynamometry. Subjects sat on the dynamometry chair with the knee at 15° and the hip at 90°. Subjects wore a compression boot, blindfold, and headphones playing white noise and signaled when movement direction (flexion or extension) was deduced. Subjects performed a total of five repetitions for each test. The middle three repetitions were used in the intrasession analysis (ICC(3,1)), and the average of the middle three repetitions between days 1 and 2 were used in the intersession reliability (ICC(3,k)) and precision analyses. Based on these analyses, TTDPM had high ICC values with low SEM values for both intrasession and intersession designs (Table 1).

Table 1. Knee Flexion/Extension Proprioception ICC and SEM

	Intrasession		Intersession	
	ICC	SEM	ICC	SEM
Flex TTDPM	0.917	0.216	0.702	0.320
Ext TTDPM	0.879	0.194	0.789	0.314
TTDPM Combined	0.776	0.326	0.917	0.160

2.6.3 Biomechanical and Neuromuscular Analysis of Single-Leg Stop-Jump

This dissertation used a single-leg stop-jump as a task to evaluate muscle activation pattern, joint position, and joint stiffness. Previously, sudden deceleration with directional changes, cutting, stopping, or other functional weight-bearing movements have been reported to be associated with non-contact ACL injuries.[220, 296-299] Many studies have utilized those functional movements to identify risk factors related to gender differences in injury rates.[200, 216, 223, 226, 227, 300-303] In addition, several studies have used hop tests to evaluate knee function and

performance in healthy, ACL-D, and ACL-reconstructed individuals in clinics and on the field.[304-310]

Many studies have reported muscle co-contraction during dynamic tasks using various calculation methods.[21, 218, 311-314] In this dissertation, muscle co-contraction is defined as the simultaneous activation of antagonistic muscles (quadriceps-hamstrings) and is calculated using the normalized EMG of each muscle group.[21] Besier and colleagues used a simple co-contraction ratio of average activation of knee flexors over extensors and reported the greater co-contraction ratio with the more demanding task (cutting).[312] Myer and colleagues utilized a co-contraction index to evaluate the medial and lateral muscle contribution on frontal plane knee rotation.[218] This dissertation focuses on muscle co-contraction ratio of knee flexors (medial and lateral hamstrings) over extensors (vastus medialis and vastus lateralis) during the pre-landing phase (150ms prior to the foot contact) and how this ratio is altered following the training intervention.

The reliability of kinematic and kinetic variables has been reported in previous studies.[315, 316] Karamanidis and colleagues evaluated various running speed and knee flexion angles at initial contact and toe-off and reported the intrasession ICC greater than 0.80.[316] Goodwin and colleagues evaluated knee flexion angular velocity and range of motion during a countermovement jump and reported ICCs of 0.79 and 0.90, respectively.[315] The same study evaluated the reliability of integrated EMG of the rectus femoris, vastus medialis, and biceps femoris and reported ICCs of 0.88, 0.70, and 0.24, respectively. Raw EMG amplitude was used instead of the normalized value, which may account for the low ICC for the biceps femoris. Komi and Buskirk showed good intra- and intersession ICCs of the biceps brachii during an isometric contraction (ICC = 0.81-0.95).[317]

Since these reliability results are not specific to this study and most studies did not report SEM values, the intersession reliability and precision of knee landing biomechanics and EMG parameters during the single-leg stop-jump task were evaluated at the Neuromuscular Research Laboratory. Reliability and precision for knee flexion angles and knee flexion moment were moderate to excellent (ICC = 0.732-0.924, SEM = 1.665-3.424 degrees) for knee flexion angle and moderate (ICC = 0.752, SEM = 0.016Nm/BW*HT) for knee flexion moment. The EMG of four thigh muscles (vastus medialis, vastus lateralis, medial hamstring, and lateral hamstring) during the pre-landing phase (150ms) demonstrated low to high reliability (ICC = 0.479-0.943); however, precision is small and similar for all muscles (SEM = 0.020-0.063%MVIC). The co-contraction ratio during the pre-landing phase is low (ICC = 0.327-0.519, SEM = 0.412-2.156). Therefore, the changes on EMG variables after the intervention were evaluated with caution.

2.6.4 Knee Separation Distance during Double-Leg Drop-Jump

In addition to biomechanical and neuromuscular analyses during a single-leg stop-jump, this study analyzed knee separation distance during a double-leg drop-jump. As stated before, both video analysis and computer simulation of non-contact ACL injuries support that valgus landing is a common mechanism of non-contact ACL injury.[219, 224, 225] A few studies reported simple ways to evaluate knee valgus loading.[318, 319] The simplest way was introduced by Noyes and colleagues who utilized a 2D video camcorder to measure the distance between two knee markers, placed on the center of each patella, as an absolute value which was then normalized by dividing by the hip distance (between the greater trochanters).[318] High correlation coefficients (ICC > 0.90) were reported for the measurement variable and statistical significant changes in the knee separation distance during the deepest point of the task in female athletes were

demonstrated after 6 weeks of neuromuscular training.[318] Ford and colleagues used a 3D motion analysis system to measure the distance between two knee markers and reported a similar correlation coefficient (ICC = 0.916).[319] In this dissertation, the knee separation distance was calculated as follows: a linear distance was determined from the coordinates of the two lateral knee markers and half of each knee width was subtracted from that linear distance. The knee separation distance was then expressed as an absolute value and as a normalized value by dividing the absolute value by the linear distance between the ASIS markers.

2.6.5 Assessment of Knee and Hip Muscle Strength

All muscle strength was assessed with an isokinetic dynamometer. The device is widely used in many disciplines to measure joint torque, angle, and velocity. The reliability and validity of the dynamometer hardware is excellent for all measurements (ICC=0.99-1.00).[320] The joint torque is influenced by several factors: morphological factors (volume, pennation angle, fiber length), moment arm length, force-length relationship, force-velocity relationship, types of contraction, and neural factors (muscle activation pattern, activation rate, motor unit synchronization).[131, 321, 322] For example, Westing and colleagues evaluated knee extensor strength during concentric, eccentric, and isometric contractions and at various angular velocities (60-360 degrees/sec) and reported different peak torques for each given condition.[323] In this dissertation, there were two strength variables: peak torque and RFD. In order to minimize the effects of confounding factors listed above, an isometric contraction at 45 degrees of knee flexion was chosen.

RFD has been investigated because of its impact on explosive movements in sports.[324-326] Aagaard and colleagues evaluated knee extensor RFD during a maximal voluntary isometric

contraction using an isokinetic dynamometer.[325] The torque was calculated over several time intervals (0-30, 0-50, 0-100, and 0-200ms, relative to the onset of contraction (above 7.5Nm)) and it was reported that RFD contributed to an enhanced neural drive in the early phase of muscle contraction (0-200ms); therefore, this interval was used in this dissertation. RFD was expressed as an absolute value (Nm/s) and a normalized value (%MVIC/s).[325] The same authors normalized RFD relative to the peak torque and determined the time to reach 1/6, 1/2, and 2/3 of peak torque after the onset, defined as 2.5% of MVIC. The change in normalized torque (%MVIC) over the change in time (seconds) was expressed as normalized RFD. Due to very early onset of 1/6 and 1/2 peak torque and potential sampling errors, the 2/3 peak torque was used for the calculation of normalized RFD.

At the Neuromuscular Research Laboratory, a pilot study revealed good reliability and precision of isometric knee flexion and extension (Flexion: ICC = 0.943 and 0.082 Nm/kg and Extension: ICC = 0.914 and 0.170 Nm/kg). In addition, the reliability of hip abduction strength assessments were moderate (ICC = 0.749 and 0.119 Nm/kg) based on this same pilot study. Reliability and precision of knee flexion and extension RFD were not evaluated.

2.6.6 Assessment of Army Physical Fitness Test

A standard Army Physical Fitness Test (APFT) was performed in this study. It is most commonly used to evaluate soldiers' fitness levels. Previously, the APFT 2 mile-run was reported to highly correlate with maximum oxygen uptake (VO2 max) and the two other muscular tests (push-ups and sit-ups) are associated with the muscular strength/endurance.[327] Several studies have reported low fitness level measured by APFT as risk factors of common musculoskeletal injuries.[2, 8-13]

3.0 METHODOLOGY

3.1 EXPERIMENTAL DESIGN

The study was an intervention study with two groups: an experimental group and a control group. The experimental group participated in an 8-week training program while the control group participated in their regular PT session. All participants in both groups were tested prior to and after the intervention program. The independent variables were group (experimental and control) and time (pre- and post-).

3.2 DEPENDENT VARIABLES

The dependent variables were categorized into isometric strength, RFD, proprioception, stop-jump joint positions, drop-jump knee separation distance, stop-jump joint stiffness, stop-jump muscle co-contraction ratio, and APFT (Table 2).

Table 2. Dependent Variable List

Categories	Dependent Variables
DV1: Isometric Strength Assessment	Knee Extension Peak Torque Normalized to Body Weight (Nm/Kg) Knee Flexion Peak Torque Normalized to Body Weight (Nm/Kg) Hip Abduction Peak Torque Normalized to Body Weight (Nm/Kg)
DV2: RFD Assessment: Absolute	Knee Extension RFD (Nm/s) Knee Flexion RFD (Nm/s) Knee Extension RFD Normalized to Peak Torque (%MVIC/s) Knee Flexion RFD Normalized to Peak Torque (%MVIC/s)
DV3: Proprioception: TTDPM	Knee Extension TTDPM (deg) Knee Flexion TTDPM (deg)
DV4: Stop-Jump: Joint Position	Knee Flexion Angle at Foot Contact (deg) Knee Valgus/Varus Angle at Foot Contact (deg) Hip Abduction Angle at Foot Contact (deg)
DV5: Drop-Jump: Knee Separation Distance	Knee Separation Distance at Max Knee Flexion during a drop-jump task (cm) Knee Separation Distance Normalized to ASIS Distance
DV6: Stop-Jump: Joint Stiffness	Knee Flexion/Extension Stiffness during Landing Phase(Nm/Kg*Ht/deg)
DV7: Stop-Jump: Co-contraction Ratio	Hamstrings/Quadriceps Co-contraction Ratio during Pre-Landing Phase (150ms prior to Initial Foot Contact)
DV8: Army Physical Fitness Test	Push-ups (reps) Sit-ups (reps) 2 mile run (min)

The specific dependent variables (DV) are as follows:

- DV1: isometric knee extension, knee flexion, and hip abduction strength measured in peak torque normalized by body mass
- DV 2: isometric knee extension and flexion RFD measured as an absolute value of torque in Newton-Meters per second and as a normalized value of %MVIC per second

- DV 3: knee extension and flexion conscious proprioception measured by threshold to detect passive motion in degrees
- DV 4: knee flexion/extension, knee valgus/varus, and hip abduction/adduction joint angles at initial foot contact during the single-leg stop-jump task
- DV 5: knee separation distance measured as an absolute value in centimeters and as a normalized separation distance (normalized by ASIS distance) at the maximal knee flexion position during the drop-jump task
- DV 6: knee extension/flexion joint stiffness measured in knee flexion moment over a range of knee flexion motion during the descending phase (from the initial foot contact to the maximum knee flexion) of a stop-jump task
- DV 7: hamstrings and quadriceps co-contraction ratio measured by the average normalized EMG of the hamstrings over the average normalized EMG of the quadriceps during the pre-landing phase (150 millisecond prior to initial foot contact) of a stop-jump task
- DV 8: Army Physical Fitness Test (push-ups in 2 minutes, sit-ups in 2 minutes, and 2 mile run time)

3.3 PARTICIPANTS

Similar intervention studies were utilized for sample size calculations.[246] Based on interaction effects between groups (experimental and control) and time (pre- and post-intervention) in a two-way mixed design ANOVA, a conservative estimate indicated that an effect size of $f = 0.50$, $df = 1$, and an alpha level of $\alpha = 0.05$ required 17 subjects in each group

for a statistical power of 0.80 (Table 3). Originally, a convenience sample of 40 subjects was to be recruited to account for a 15% attrition rate.[328] This subject number was greater than previous studies.[56-63] All subjects were selected from one battalion (approximately 500+ soldiers), based on their availability during the length of the training program. This battalion is an aviation support unit with similar military occupation specialties; therefore, all soldiers within this battalion were exposed to similar physical training sessions and occupational demands throughout their Army careers. One company commander and the soldiers in his company volunteered to participate in the research and they served as the experimental group. Another company was assigned to send subjects and this group served as the control group. All subjects met the inclusion and exclusion criteria. Subjects in the control group were to be matched for gender, age (within 5yrs), and physical activity level as indicated by APFT score (within 30 points).

Table 3. Power Analysis

Dependant Variables	Group	Time (Pre)	Time (Post)	Grand Mean	SD	Sm (AB)	*f* (AB)	Estimated N
Strength Knee Extension (in Nm/Kg)	Exp	211	227	216	7.6	4.6	0.6	12
	Con	211	214					
Peak Knee Flexion Angle (in degrees)	Exp	62	96	70	11.1	5.69	0.51	17
	Con	63	70					
Peak Knee Flexion Moment (in Nm/Kg*HT)	Exp	0.076	0.059	0.073	0.01	0.005	0.54	16
	Con	0.079	0.076					

3.3.1 Inclusion Criteria

- Participation in regular physical training without any injury profiles
- Participation in regular physical training at least 5 days a week

3.3.2 Exclusion Criteria

- Subjects with previous history of major lower extremity injuries that required surgery
- Subjects with insulin dependent diabetes mellitus, rheumatologic disorder, cerebral vascular disorder, cardiovascular or pulmonary disease or any other central or peripheral disease that might interfere with sensory input
- Subjects who were currently and knowingly pregnant – defined as any subjects who were unable to definitively state that she is not pregnant
- Subjects with any pain during maximal muscle contractions

3.4 NONLINEAR PERIODIZED TRAINING PROGRAM

Each training session consisted of a warm-up, the main exercise, supplemental exercises, and the conclusion. Each section and exercise selection is described in details below. Lists of exercises weekly are found in Appendix A. All training sessions were conducted and led by a certified strength and conditioning coach.

3.4.1 Warm-up

Each session began with a dynamic warm-up. Dynamic warm-up exercises covered the main working muscles and movements while increasing heart rate, oxygen consumption, body temperature, and muscle/tendon elasticity.

3.4.2 Main Exercises

The training program consisted of resistance training, fast/speed endurance training, interval endurance, and long endurance. Each session and exercise selections are described below.

3.4.2.1 Resistance Training

There were two resistance training sessions per week. The first resistance training session covered body weight resistance and unstable surface resistance exercises. The second resistance training session covered explosive lifting and dumbbell resistance exercises. The first resistance session targeted muscular strength and endurance. The second resistance session focused on building strength and explosive power during multi-joint movement.

The first resistance training session was of moderate intensity (level 1-3) with high repetitions (10+) and a gradual increase in sets (1-3 sets) during week 1 to week 4. The training goal/focus was shifted to challenge higher speed and muscular endurance on week 5 and week 6 by switching repetitions to a time interval (20-30s). Soldiers rotated to each station in a circuit manner to control the work and rest ratio. The intensity and volume were decreased for weeks 7-8 to prepare for the test.

The explosive power was achieved with moderate intensity and repetitions (5+). All multi-joint exercises were technical and difficult to master; therefore, the first two weeks were dedicated to teaching and mastering good technique all of the multi-joint exercises.

3.4.2.2 Fast/Speed Endurance Training

Fast/speed endurance training consisted of several training modes: plyometrics, short sprints (20yds up to 200m), and agility and ladder drills. Plyometric training intensity and volumes were carefully monitored and introduced according to safety recommendation.[329, 330] In general, most soldiers are not accustomed to doing plyometric exercises on a regular basis. Therefore, the plyometric training volume was limited to 100 counts per session and the jump intensity was limited to jumps-in-place, standing jumps, multiple hops/jumps, and small box drills with no depth jumps. Four to six exercises were selected per session.

Short sprints were designed to teach soldiers running form for speed and to build speed endurance. Sprint workouts included short sprint repetitions (10-60 seconds), all-out sprints for 30-120 yds, one minute sprint (400m lap run), and pickup sprints (combination of walk, stride, sprint, walk for 25m each).[331] Other forms of speed training such as over-speed training and resistance sprint training were not used in the study.

Agility and ladder drills were included in the session. Main agility exercises were line and cone drills (Pro Agility, T-Drill, 20-yd Square, Carioca, Zigzag, 40-yd ladder Sprint).[332]

3.4.2.3 Interval Endurance Training

The purpose of interval pace training was to stress aerobic capacity through a single session of intermittent running. The duration of each running interval was between 3-5 minutes with an intensity at or near VO2 max. The rest time was equal to or less than the running interval. Running faster than VO2 max pace does not necessarily produce a greater aerobic involvement; therefore, the interval pace was carefully monitored individually (separated into three groups).[71] Interval endurance training was a main component of the program and was scheduled once a week. The number of sets was gradually increased until phase IV, which was

designed for tapering and peak performance. In order to ease the mental stress of repeating the same exercises over, the interval duration, distance, and rest ratio were varied throughout the 8 weeks with a small reduction in volume at week 5.

3.4.2.4 Long Endurance

Long endurance days were scheduled on Fridays or the day before weekend leave, depending on the schedule. Each week either a foot march or long run was performed. The foot march was performed on weeks 1, 3, 5, and 7 at the minimum pace of 3 miles per hour (20min per mile) as per Fort Campbell Standard. Since this training program was only 8 weeks in duration, it began with a 3 to 9 mile march with a 0-30 lb rucksack, depending on the soldiers' previous experiences. 10 minute rests were given every 3 miles. The duration was gradually increased by a half mile per march. Every foot march was recorded for time.

There were two types of long endurance running training: marathon pace and threshold pace. The marathon pace running was to provide soldiers the chance to get comfortable with the distance. The distance increased from 3 to 6 miles initially to 6-9 miles by week 8. The marathon pace run was used on week 2 and week 6. Threshold pace is great for improving endurance. The intensity of threshold pace was "comfortably hard" or 24-30 seconds per mile slower than 5K race pace. The duration of threshold pace can be either a tempo run for 20-60 minutes or cruise intervals consisting of a15 minute run and a 3 minute rest for 20-60 minutes total. The running target speed for marathon and threshold paces was determined and estimated by 2 mile run time.[71]

3.4.3 Supplemental Exercises

Main exercises were followed by supplemental exercises. These exercises consisted of balance training, shoulder exercises, neck/back exercises, and exercises that targeted running muscles. The aim of these sessions was to educate soldiers about injury prevention and techniques of preventative exercises for common orthopedic injuries associated with tactical athletes.

3.4.4 Session Conclusion

Following the Supplemental Exercises, there was time for everyone to exchange opinions and for feedback. This time was also used to announce the training plan for the next day or week.

3.5 INSTRUMENTATION

3.5.1 Video Motion Analysis System

Biomechanical analyses of the single-leg stop-jump and the double-leg drop-jump were performed using a 3-D motion analysis system and force plates. The Nexus Motion Analysis System (Vicon, Centennial, CO) was used for the analyses, with six high-speed (200 Hz) optical cameras placed at a distance of 4 meters around one force plate. The capture volume was set during the calibration process covering the area for both the stop-jump and drop-jump tasks. The

camera calibration was performed using the wand calibration method according to the manufacturer's guidelines.

Ground reaction forces were collected on a Kistler 9286A (Kistler Instrument Corp.; Amherst, NY, U.S.A.) piezoelectric force sensor platform. The Kistler force platform was interfaced with a personal desktop computer via a 32-channel analog to digital (A/D) converter board. All data were recorded using the Nexus Motion Analysis System Software Version 1.3. The ground reaction force data were collected at 1,200 Hz during the single-leg stop-jump and double-leg drop-jump.

3.5.2 Electromyography (EMG)

Electromyographic activity was assessed with the ZeroWire System (Aurion S.r.l., Milano, Italy). The ZeroWire System has the following specifications (input impedance: 20MOhm; common mode rejection ratio (CMRR): 90dB; signal-to-noise ratio (SNR): >50dB; current gain: x1000; hardware filtering: an analog RC (resistor-capacitor) filter; high-pass and low-pass with the bandwidth of 10-1000 Hz; and slopes of the cutoffs: 6dB/octave).

Electromyographic signals from the Ag/AgCl pre-gelled bipolar surface electrodes with 10mm in diameter and a rectangular shape (Medicotest, Inc. Rolling Meadows, IL) were passed to a portable battery-operated WIFI transmitter placed adjacent to their respective electrodes, sent to a receiver, and stored on a personal computer for further analysis. EMG data were sampled at a rate of 1200 Hz and recorded using the Nexus Motion Analysis System Software Version 1.3.

3.5.3 Biodex Isokinetic Dynamometer

Knee and hip muscle strength and knee RFD were assessed with the Biodex System III Multi-Joint testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY). Torque values were automatically adjusted for gravity by the Biodex Advantage Software v.3.2 (Biodex Medical Inc., Shirley, NY). The calibration of the Biodex dynamometer was performed according to the specifications outlined by the manufacturer's service manual. The trial-to-trial and day-to-day reliability and validity of torque measurements of the Biodex System III have been reported previously with an ICCs ranging from 0.99-1.0.[320]

Knee proprioception was also assessed with the Biodex System III Multi-Joint testing and Rehabilitation System. A PresSsino Gradient Sequential Compression Unit (Chattanooga Group, Hixson, TN) was applied to each subject's lower leg during knee flexion and extension TTDPM testing to minimize the skin pressure and movements.

3.6 TESTING PROCEDURES

3.6.1 Subject Preparation

A written informed consent form, approved by the Institutional Review Board of the University of Pittsburgh and the Dwight David Eisenhower Army Medical Center, was signed by each subject prior to participation. All subjects were screened for inclusion and exclusion criteria and then subjects completed the demographic information form (Appendix B). All laboratory testing took place at the Human Performance Research Center (a satellite laboratory of the

Neuromuscular Research Laboratory, University of Pittsburgh), which is located in the Clarksville Base Gym on the Fort Campbell, KY, US Army Post.

3.6.2 Order of Testing

The laboratory testing was conducted in the following order: hip strength, knee strength, knee TTDPM, single-leg stop-jump, and two-leg drop-jump. All subjects were tested before and after the 8 week intervention program. Since push-ups, sit-ups, and 2 mile-run were administered as a group, all subjects in each group performed these tests together within one week of the beginning and the end of the 8 week intervention program.

3.6.3 Knee and Hip Strength Testing

For knee flexion and extension strength testing, subjects sat in a comfortable upright position on the Biodex dynamometer chair and were secured using thigh, pelvic, and torso straps in order to minimize extraneous body movements and momentum (Figure 9). The lateral femoral epicondyle was used as the bony landmark for aligning the axis of rotation of the knee joint with the axis of rotation of the dynamometer. The knee was locked at an angle of 45 degrees of flexion for this testing. During the testing, subjects were asked to hold the chair handles with their hands and were given verbal encouragement (not aggressive verbal encouragement) in an attempt to achieve maximal effort.[333-335] Subjects were asked to perform three knee flexion and extension isometric contractions on their dominant limb. The verbal instruction to generate torque “as forcefully as possible” was given to subjects prior to every single trial to ensure consistency of the verbal instruction.[324, 336] A verbal cue of “ready, set, go,” was given and the

subjects contracted the knee flexors and extensors, alternating, for 5 seconds. There was a 10-second rest between each contraction.

Figure 9. Knee Flex/Ext Strength Testing

For hip abduction testing, subjects lay on the non-test side with test hip slightly abducted. The bottom leg was securely strapped down and the top leg was strapped to the dynamometer hip attachment. The hip joint center was estimated from the greater trochanter and aligned with the axis of the dynamometer. Subjects were asked to perform three hip abduction isometric contractions of their dominant limb. The verbal instruction and testing procedures were the same as in the knee testing described above.

3.6.4 Knee Proprioception Testing

3.6.4.1 Knee Flexion/Extension Threshold to Detect Passive Motion

Subjects were tested in a seated position, blindfolded and with their ears covered by headphones playing white noise to eliminate visual and auditory cues (Figure 10). An inflated pneumatic sleeve was placed around the lower leg to minimize any tactile feedback between the dynamometer and the limb.[337] The pneumatic sleeve was inflated to 30mmHg. The test was started with the knee positioned at 45 degrees of flexion. The subjects were instructed to press a

stop-button as soon as they felt motion and could identify the direction of the movement. The detection of direction in addition to the sense of movement was used to minimize the false responses, as suggested in previous studies.[338, 339] At an unannounced time (0-30 seconds after instruction), the knee was passively moved into either flexion or extension at a rate of 0.25 degrees/second. The difference between the initiation position and the final position was recorded in degrees. Five repetitions for flexion and five repetitions for extension were randomly performed. If a subject indicated the wrong direction, the trial was not counted.

Figure 10. Knee Flexion/Extension TTDPM Testing

3.6.5 Single-leg stop-jump and double-leg drop-jump

The following anthropometric measurements were taken using height and weight scales, anthropometric calipers, and a tape measure (Figure 11):

- Height – the vertical distance between the top of the head and the bottom of the feet
- Weight – subject's mass measured on a standard weight scale
- Knee width – the maximum breadth of the knee across the femoral epicondyles
- Ankle width – the maximum distance between the medial and lateral malleoli

Figure 11. Anthropometric Measurements

Passive reflective markers, secured with double-sided tape, were placed bilaterally on the following anatomical landmarks (Figure 12):

- ASIS
- Posterior Superior Iliac Spine (PSIS)
- Knee joint line – the lateral femoral epicondyle
- Lateral malleolus
- 2nd metatarsal head (dorsal aspect)
- Heel (posterior aspect)
- Mid-calf – the most lateral point at the level of the maximum circumference of the calf
- Mid-thigh – the most lateral point at a level midway between the trochanteric and tibial landmarks

Figure 12. Marker Placement

Surface electrodes were placed over the appropriate muscle belly in line with the direction of the fibers with a center to center distance of approximately 20 mm.[340] Electrode sites were shaved with an electric shaver, lightly abraded, and cleaned with 70% isopropyl alcohol to reduce impedance. Electrodes and EMG wires were securely taped down. The EMG wires were connected to a transmitter adjacent to the electrodes. The following muscles were evaluated during a single-leg stop-jump task, with the electrodes placed according to recommendation by Cram, Kasman, and Holtz (Figure 13):[341]

- vastus medialis – 2 cm medially from the superior rim of the patella and the distal third of the vastus medialis (palpation for the vastus medialis was done while isometrically contracting the quadriceps in the knee extended position)
- vastus lateralis – 3 to 5 cm above the patella, on oblique angle just lateral to midline (palpation for the vastus lateralis was done while isometrically contracting the quadriceps in the knee extended position)

- medial hamstring – parallel to the muscle fibers on the medial aspect of the thigh, 3 cm in from the lateral border of the thigh and half the distance from the gluteal fold to the back of the knee (palpation for the medial hamstrings was done while manually muscle testing with the knee at 90 degrees of flexion and the thigh in a neutral position)
- lateral hamstring – parallel to the muscle fibers on the lateral aspect of the thigh 2/3 the distance between the trochanter and the back of the knee (palpation for the lateral hamstrings was done while manually muscle testing with the knee at 90 degrees of flexion and the thigh in slight lateral rotation)

Figure 13. EMG Electrodes Placement

Once EMG and marker preparation were finished, a static trial was collected for each subject using the Nexus Motion Analysis System. During the static trial, subjects stood with their feet shoulder width apart. The joint angles were used in data processing.

White tape was placed on the floor at 40% of the subjects' height away from the force plate (Figure 14). Subjects stood on their dominant leg and hoped toward the center of force plate. All subjects were instructed on how to perform the task and practice trials were included. Subjects were instructed to jump as high as possible immediately after the first landing. Subjects

performed a total of three trials. If subjects missed the force plates or failed to jump up after an initial foot contact with force plates, the trial was repeated.

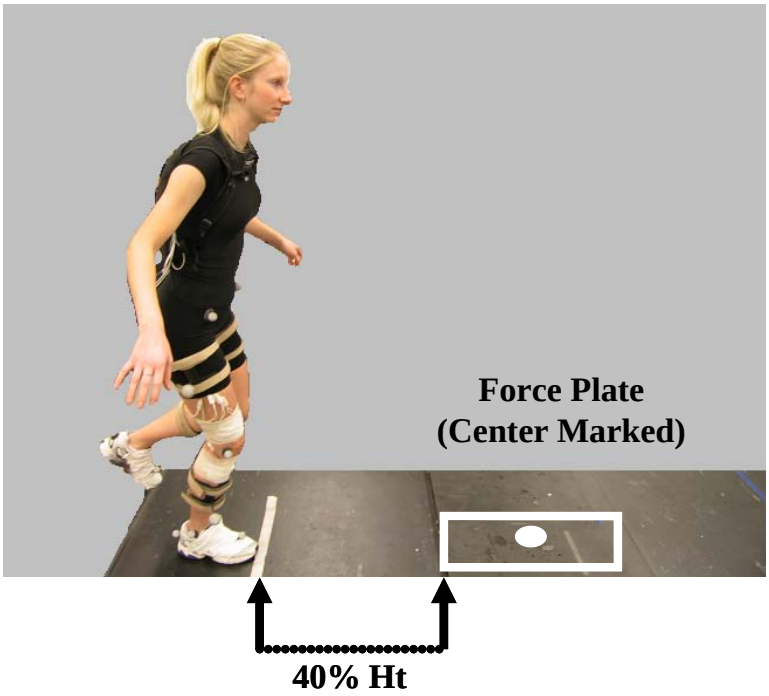


Figure 14. Single-Leg Stop-Jump Task

For double-leg drop-jump, subjects stood on a 12-inch high box platform that was placed in front of the force plates (Figure 15). Subjects were instructed to drop off from the box, land with one foot on each of the force plates, and jump as high as they could immediately after landing. A demonstration and practice trials were provided prior to the real trials. No specific instructions were given to subjects on landing or jumping techniques. Subjects performed a total of three trials. If subjects missed the force plates or failed to jump up immediately after an initial foot contact, then the trial was repeated.

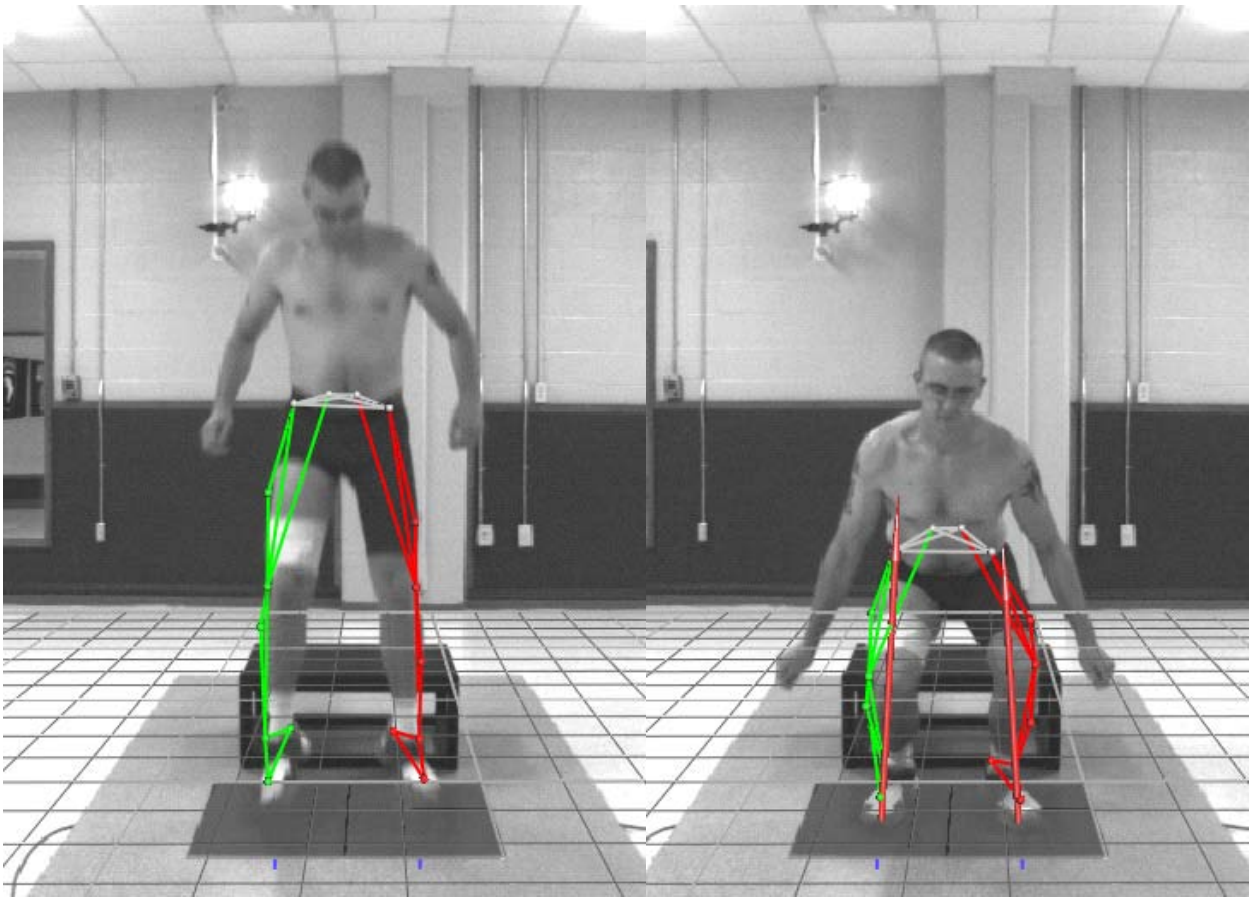


Figure 15. Double-Leg Drop-Jump Task

3.6.6 Army Physical Fitness Test

The APFT was administered during the first week of the study. The administration of the APFT was done according to the field manual 21-20.[1] Subjects completed all three events within two hours, in the order of push-ups, sit-ups, and 2 mile-run. Subjects were allowed to take no less than 10 minutes, but ideally no more than 20 minutes, to recover between each event.

Push-ups were performed with the hands in a comfortable position and the feet together or up to 12 inches apart. Subjects lowered their entire body as one unit until the upper arms were at least parallel to the ground and then lifted their entire body as the elbows were fully extended.

Any push-ups performed incorrectly were not counted. Subjects performed as many push-ups a as they could in 2 minutes.

Sit-ups were performed from the starting position of lying on their backs with the knees bent at 90 degrees. Their feet could be together or up to 12 inches apart. Hands were interlocked and placed behind the head. Subjects lifted their body to at least a vertical position and then lowered their body until the hands hit the ground. Subjects performed as many sit-ups as they could in 2 minutes.

The two mile-run was performed on the level ground with no more than a 3 degree incline or decline in slope. Subjects were encouraged to run as fast as they could.

3.7 DATA ANALYSIS

3.7.1 Data Reduction

3.7.1.1 Knee and Hip Strength Testing

The Biodex Advantage Software v.3.2 was used to obtain the maximal knee flexion/extension torque and hip abduction torque. The maximal torque was then divided by the subject's body mass and expressed in Nm/kg (Figure 16).

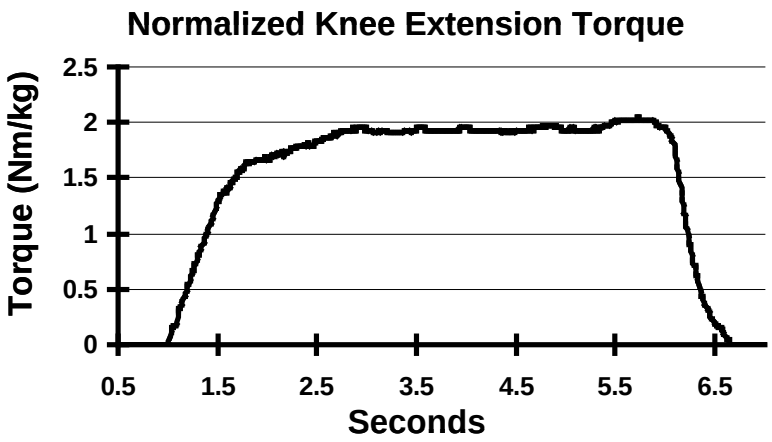


Figure 16. Maximum Knee Extension Torque

There were several steps to calculate RFD of knee extension and knee flexion. First, raw torque data were exported from the Biodex software as a text file. Second, onset of torque and time were determined (Figure 17: Ta and a). Onset of torque was set as torque exceeding 7.5 Nm.[325] Third, torque and time at 200ms past the onset was determined (Figure 17: Tb and b). RFD was calculated as the change in torque over the change in time: RFD = ΔTorque (Nm) / ΔTime (s) (Figure 17).[325] Normalized RFD was calculated using a %MVIC instead of Nm: Normalized RFD = ΔTorque (%MVIC) / ΔTime (s) (Figure 18). The onset of normalized torque was set as a point above 2.5%MVIC, and the 2/3 MVIC (66.7% MVIC) was used as an end point.[325]

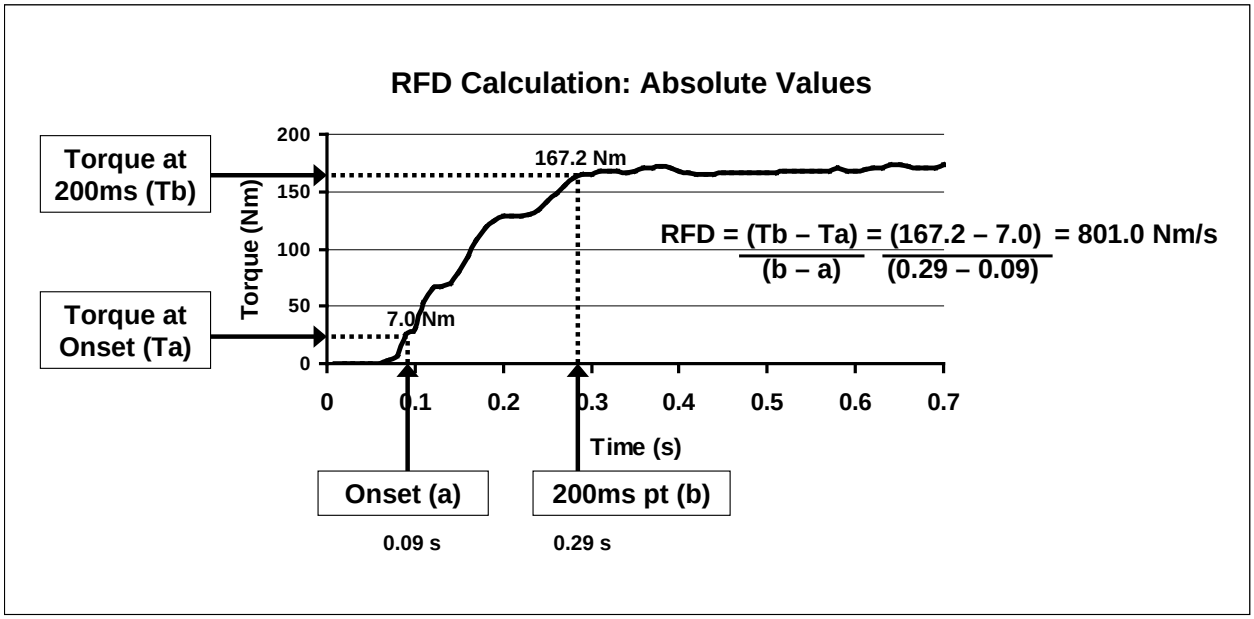


Figure 17. RFD Calculation: Absolute Values

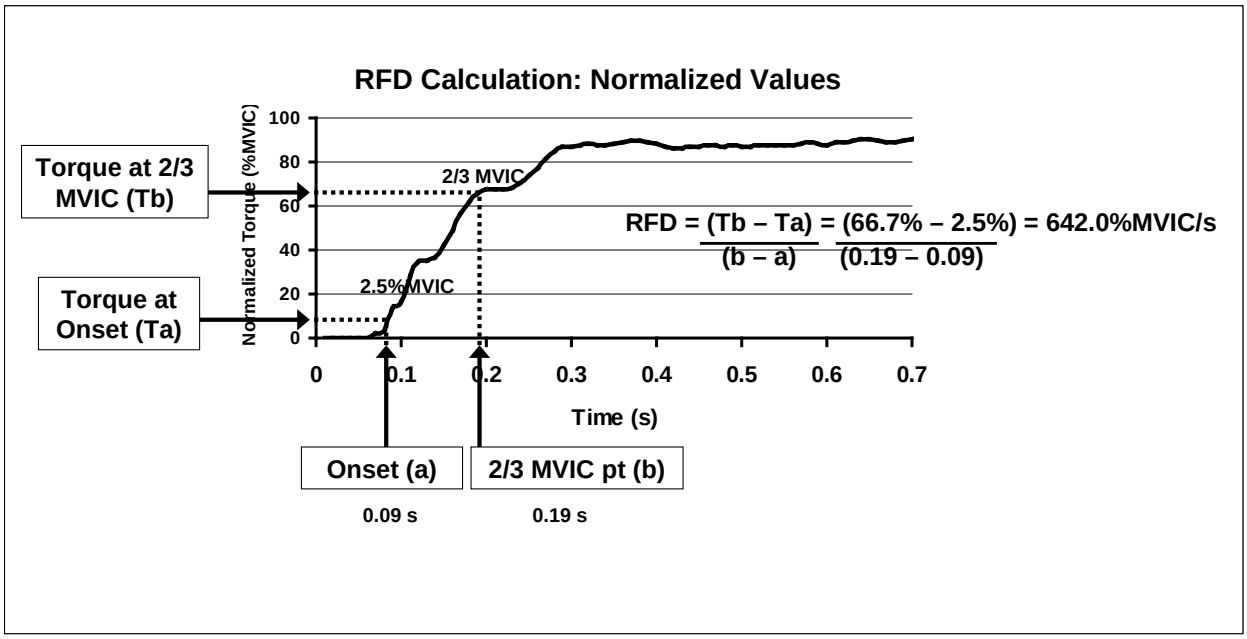


Figure 18. RFD Calculation: Normalized Values

3.7.1.2 Knee Proprioception Testing

TTDPM was measured using the Biodex System 3 Research Toolkit. The initial angle was recorded first. When subjects sensed the dynamometer moving and could identify the direction of movement, they were asked to press a stop button. The Research Toolkit showed the final joint angle (Figure 19). The initial and final angles were recorded on a piece of paper. The difference between the initial and final angles was TTDPM in degrees.

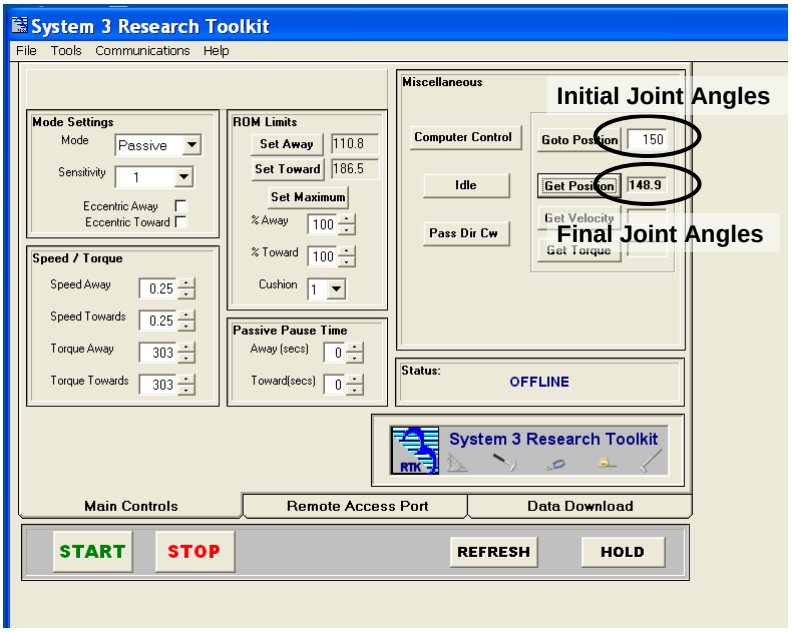


Figure 19. TTDPM on Research Toolkit

3.7.1.3 Single-Leg Stop-Jump and Double-Leg Drop-Jump Assessment

The raw coordinate data were filtered using an optimal cutoff frequency.[342] Reflective markers were used to define the 3D coordinates of each segment and joint. The raw analog data from the force plate were used to calculate the GRFs. Inverse dynamics were used to calculate the joint moments by combining the joint angles, GRFs, and anthropometrics data[343] (Appendix C). Inverse dynamic techniques involved sequential solutions of the Newton-Euler equations of

motion for each body segment.[344] Inverse dynamics calculations were performed by the pipeline module of the Nexus Software package.

First, the knee flexion angle was obtained from the static trial. Second, the knee flexion angle from the static trial was subtracted from the knee flexion angle during the single-leg stop-jump trials. Then, the inverse dynamics calculations were performed to calculate the net knee joint moment. Once the joint position and joint moments were calculated for each time frame, the leg stiffness in the sagittal plane was calculated.

The leg stiffness was calculated as the change in joint moment divided by the change in joint angle during a landing phase of a single-leg stop-jump: $k(\text{joint}) = \Delta M(\text{joint}) / \Delta\Theta(\text{joint})$.[190] The landing phase was from the initial foot contact (IC) to the maximum knee flexion angle (Figure 20). The initial foot contact was defined as the point at which the vertical GRF was equal to or greater than 5N. The leg stiffness during the landing phase of the stop-jump was calculated as (max knee flexion moment – min knee flexion moment) / (the knee flexion angle at max moment – the knee flexion angle at min moment) (Figure 21).

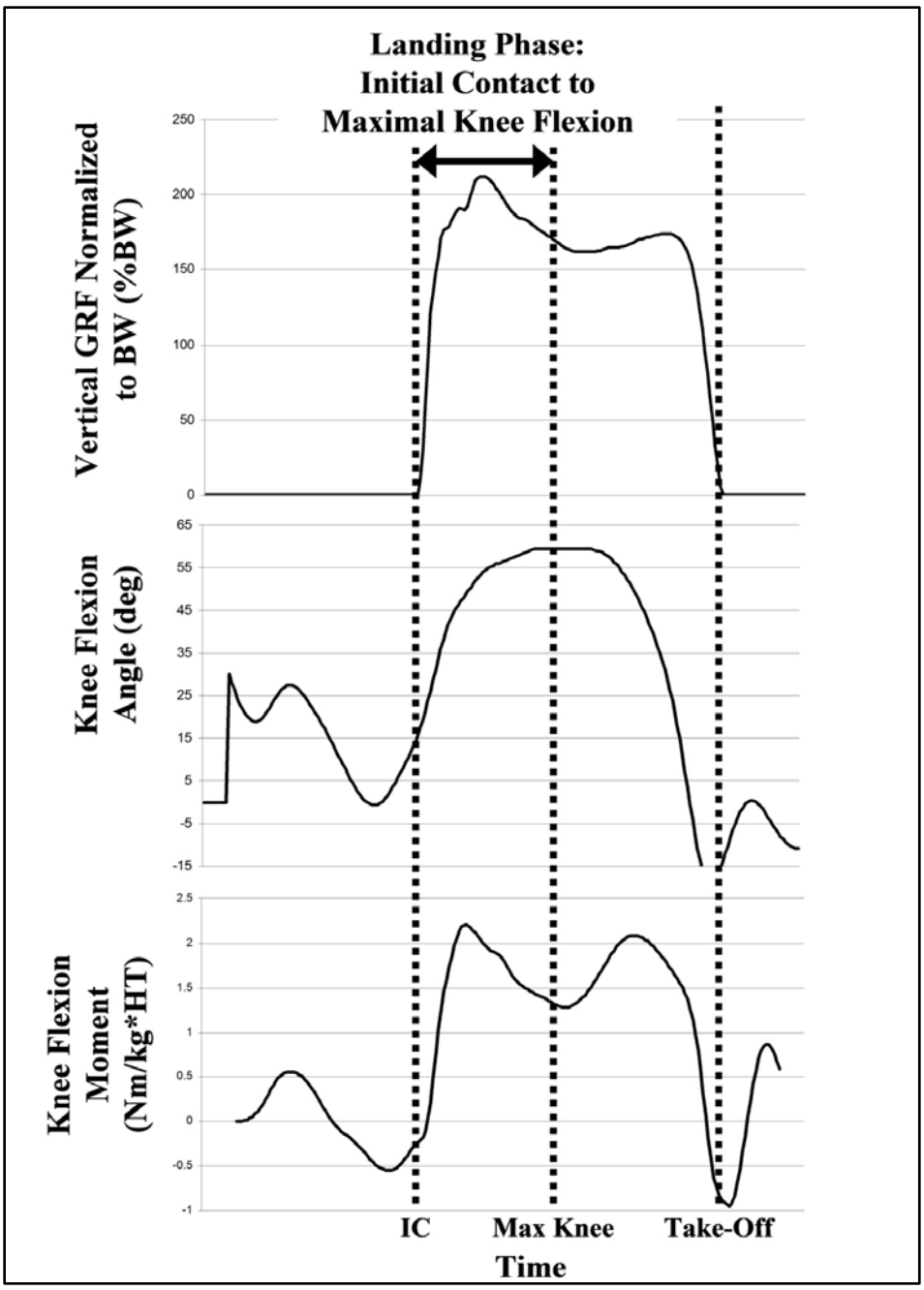
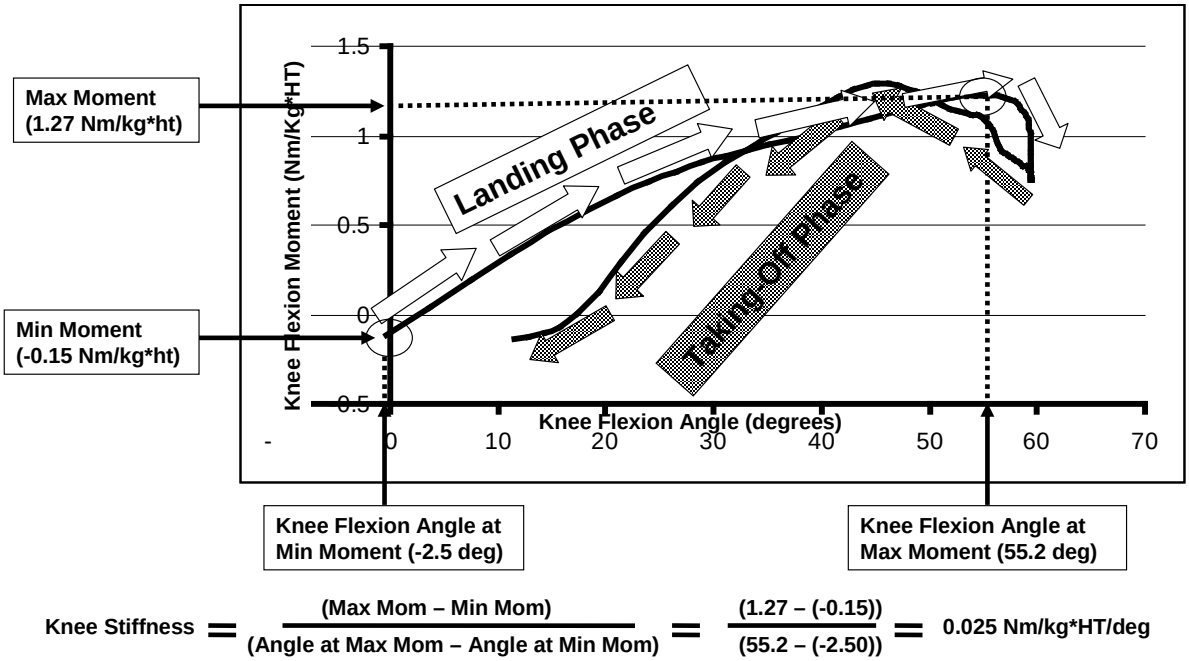


Figure 20. GRF, Knee Flexion Angle and Moment during Single-Leg Stop-Jump



$$\text{Knee Stiffness} = \frac{\text{(Max Mom – Min Mom)}}{\text{(Angle at Max Mom – Angle at Min Mom)}} = \frac{\text{(1.27 – (-0.15))}}{\text{(55.2 – (-2.50))}} = \text{0.025 Nm/kg*HT/deg}$$

Figure 21. Knee Stiffness Calculation during Single-Leg Stop-Jump

All calculations were done by a custom-designed MATLAB program (Release 12, The MathWorks, Natick, MA). First, the offsets were taken by subtracting the mean from the entire trial data. Second, the data were rectified. Third, the rectified data were passed through a fourth order, zero-phase lag, low-pass Butterworth filter with cutoff frequency of 12 Hz. The analog EMG signals during maximal isometric strength data were sorted from the highest to the lowest values. The average of the top 100 data points were used to define the maximal value of MVIC. The trial EMG data were normalized as a percentage of this maximal value. In order to evaluate the pre-landing muscle activation, the average of the normalized EMG during 150ms (prior to the initial contact) was calculated (Figure 22). The average EMG of the vastus medialis and the vastus lateralis were averaged and represented the quadriceps preactivation (%MVIC) (Quad EMG) (Figure 22). The average EMG of the medial and the lateral hamstrings were averaged

and represented the hamstrings preactivation (%MVIC) (Ham EMG). Finally, the co-contraction ratio was calculated by simply dividing Ham EMG over Quad EMG.

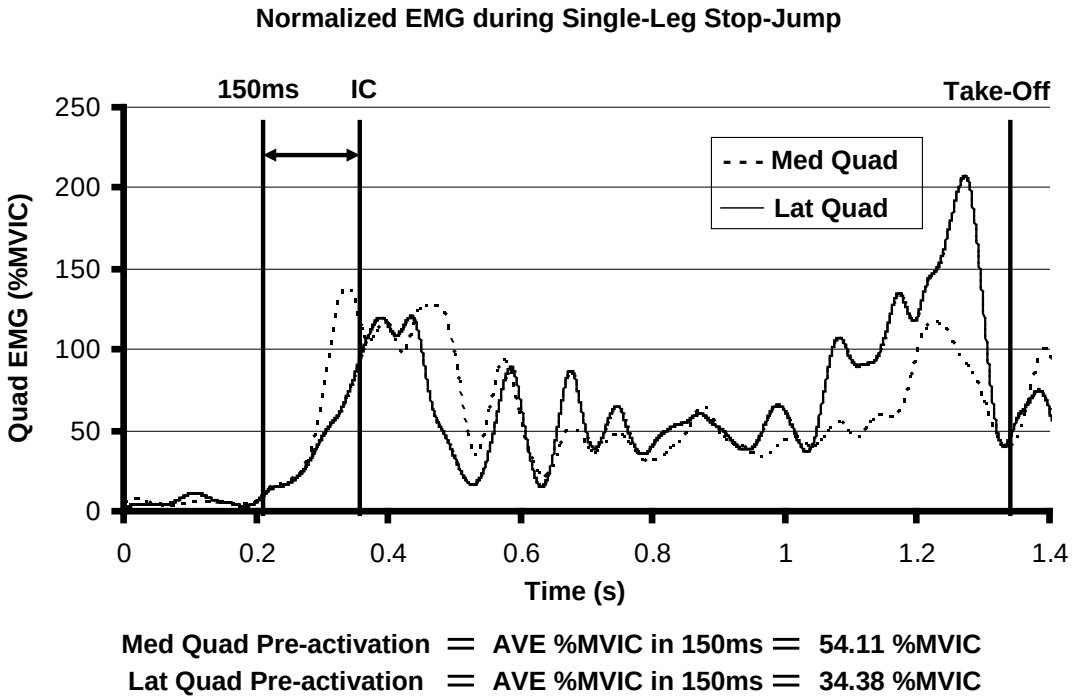


Figure 22. Filtered Quadriceps EMG normalized to MVIC

The knee separation distance at maximal knee flexion was calculated with the 3D coordinates of the knee markers, ASIS markers, and anthropometric measurements of knee width. First, the distance between the right and left knee markers on the three dimensions of x, y, and z was calculated using the distance formula: square root of ((x2-x1)^2 + (y2-y1)^2 + (z2-z1)^2). The distance between the right and left ASIS markers (inter ASIS distance) were also calculated using the same formula. The absolute knee separation distance was the distance between the two knee markers minus half the knee width for each side: Knee Separation Distance = Knee Marker Distance – (1/2 Knee Width)*2. The normalized values were also calculated by dividing the absolute knee separation distance by the inter ASIS distance (Figure 23).

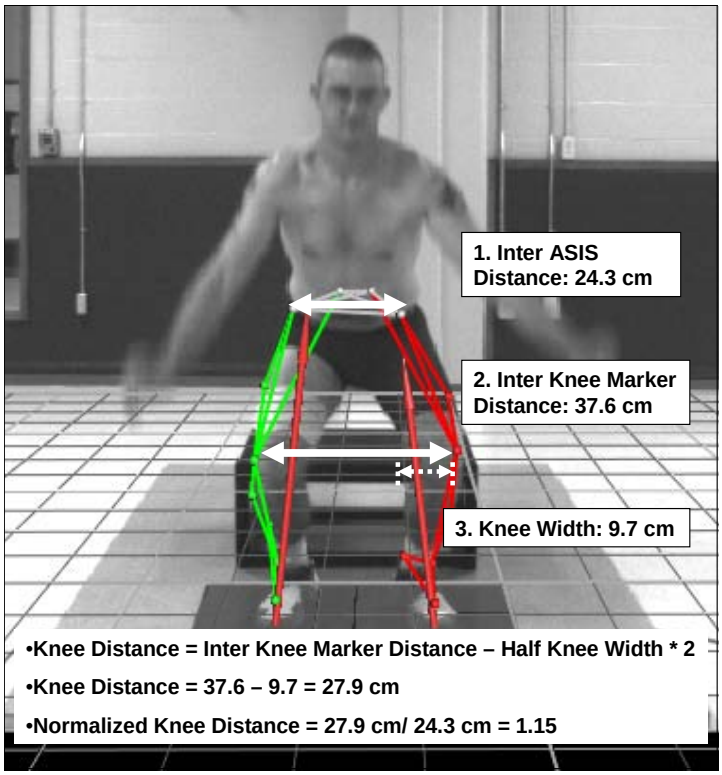


Figure 23. Knee Separation Distance Calculation during Double-Leg Drop-Jump

3.7.2 Statistical Analysis

A 2 x 2 mixed-design analysis of variance (ANOVA) was used to assess the effects of the intervention for each variable as a function of group (control and experimental) and time (pre- and post-intervention). All data were screened for assumptions of ANOVA: outliers, Shapiro-Wilk tests of normality, and Brown-Forsythe test of homogeneity of variance. An outlier is defined as an observation that is outside the overall pattern of a distribution and which fell more than 1.5 times the interquartile range above the third quartile.[345]

The between-subject independent variable was the intervention groups with two levels: control group and experimental group. The within-subject independent variable was the time with two levels: pre- and post-intervention. A significance value was set at $p = 0.05$ *a priori.* If

there was a significant interaction detected by ANOVA, the mean values for pre- and post-training for both groups were used to determine if the significance was in the positive or negative direction.

4.0 RESULTS

A total of 52 soldiers were enrolled in the study (28 in the experimental group and 24 in the control group) and a total of 36 soldiers completed the study (23 in the experimental group and 13 in the control group). A significant number of soldiers did not return for post-testing due to block leave, deployment, or the development of medical conditions unrelated to the study or its training that prevented testing. The attrition rate was 30.8%.

The experimental group had a total of 40 potential training sessions planned: 5 working days x 8 weeks. During the study period , there were 8 days of holidays given to the soldiers. Because these holidays were often on Friday, Friday sessions were held less frequently (Mondays 6/8, Tuesdays 7/8, Wednesdays 8/8, Thursdays 7/8, and Fridays 4/8). Out of 32 available training sessions, the soldiers in the experimental group participated in 58.9% of sessions, on average.

A total of 36 soldiers completed the study (23 males in experimental, 13 males in control). Originally, subjects were to be matched for gender, age (within 5yrs), and physical activity level as indicated by APFT score (within 30 points). However, due to a lack of pre-training APFT data on the control group and a lack of female soldiers, subjects were matched only on age. There were no statistically significant differences in demographics between the two groups (Table 4).

Table 4. Demographics

	CON		EXP		
	MEAN	SD	MEAN	SD	p
Age (years)	24.2	3.5	27.0	6.4	0.159
Height (cm)	176.8	6.8	174.8	8.7	0.483
Weight (kg)	79.6	14.1	77.6	19.9	0.752

4.1 STRENGH

Mean strength data normalized to body weight for all tests are presented in Table 5. All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed; all assumptions for ANOVA were met. The ANOVA revealed that there were no significant training effects on knee flexion strength ($F(1,34) = 0.231$, $p = 0.634$), knee extension strength ($F(1,34) = 0.320$, $p = 0.575$), or hip abduction strength ($F(1,34) = 1.522$, $p = 0.226$).

Table 5. Strength Normalized to Body Weight

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Knee Flexion Strength (Nm/kg)	Pre	1.41	0.41	1.31	0.30	0.634
	Post	1.39	0.40	1.33	0.36	
Knee Extension Strength (Nm/kg)	Pre	2.31	0.37	2.29	0.45	0.575
	Post	2.23	0.52	2.29	0.46	
Hip Abduction Strength (Nm/kg)	Pre	1.85	0.20	1.75	0.37	0.226
	Post	1.78	0.17	1.80	0.38	

4.2 RATE OF FORCE DEVELOPMENT

Mean RFD data normalized to body weight for all tests are presented in Table 6. All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed; all assumptions for ANOVA were met except for pre and post knee flexion normalized RFD. Normality was violated for knee flexion normalized RFD for the following as defined in Table 6: CON-PRE (Shapiro-Wilk: $W = 0.775$, $p = 0.004$), CON-POST (Shapiro-Wilk: $W = 0.650$, $p < 0.001$), EXP-PRE (Shapiro-Wilk: $W = 0.806$, $p < 0.001$), and EXP-POST (Shapiro-Wilk: $W = 0.859$, $p = 0.004$). A stem-and-leaf table from SPSS revealed that there was one extreme outlier (defined as 3.0 x Interquartile Range) in the control group and one outlier (defined as 1.5 x Interquartile Range) in the experimental group on pre knee flexion normalized RFD (Table 7).[345] After removing the outliers from the control group (#1) and from the experimental group (#18), all assumptions for ANOVA were met.

Table 6. Knee Rate of Force Development Normalized to Body Weight

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Knee Flexion RFD Absolute (Nm/s)	Pre	440.1	133.0	402.1	128.3	0.317
	Post	442.4	127.1	434.6	159.4	
Knee Extension RFD Absolute (Nm/s)	Pre	705.6	157.8	680.1	241.8	0.402
	Post	663.8	166.6	682.9	277.8	
Knee Flexion RFD Normalized (%MVIC/s)	Pre	642.8	128.6	656.1	199.8	0.150
	Post	546.6	101.1	660.9	150.3	
Knee Extension RFD Normalized (%MVIC/s)	Pre	894.3	265.4	847.7	194.4	0.412
	Post	722.2	192.1	745.5	272.1	

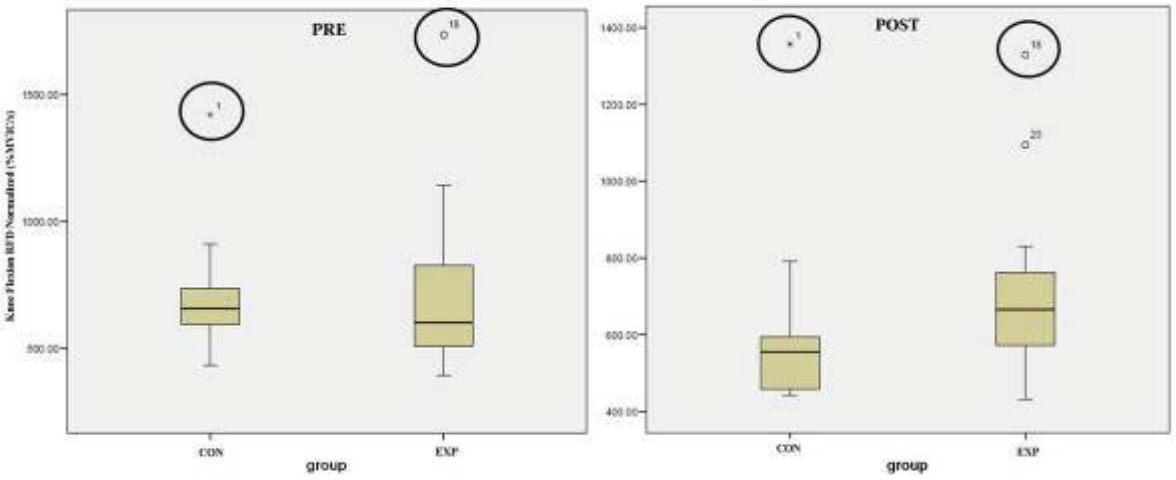


Figure 24. Stem-and-leaf Plot and Outliers on Knee Flexion RFD Normalized (PRE and POST)

The ANOVA revealed that there were no significant training effects on knee flexion RFD ($F(1,34) = 1.030$, $p = 0.317$), knee extension RFD ($F(1,34) = 0.719$, $p = 0.402$), knee flexion RFD normalized ($F(1,32) = 2.170$, $p = 0.150$), or knee extension RFD normalized ($F(1,34) = 0.689$, $p = 0.412$).

4.3 PROPRIOCEPTION

All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed. All TTDPM data were positively skewed and violated the assumption of normality (Table 7). Usually, ANOVA is robust against violations of normality as long as a variable is skewed in the same direction across all cells of the design.[346] Therefore, no transformation of data was used for the analyses. A stem-and-leaf table

from SPSS revealed that there were a few extreme outliers in each group (Figure 25). Those extreme outliers were removed from the analyses.

Table 7. Shapiro-Wilk Test of Normality

		CON			EXP		
		W	df	p	W	df	p
TTDPM Toward Flexion (degree)	Pre	0.654	13	0.01	0.578	23	0.01
	Post	0.837	13	0.02	0.492	23	0.01
TTDPM Toward Extension (degree)	Pre	0.580	13	0.01	0.803	23	0.01
	Post	0.741	13	0.01	0.657	23	0.01

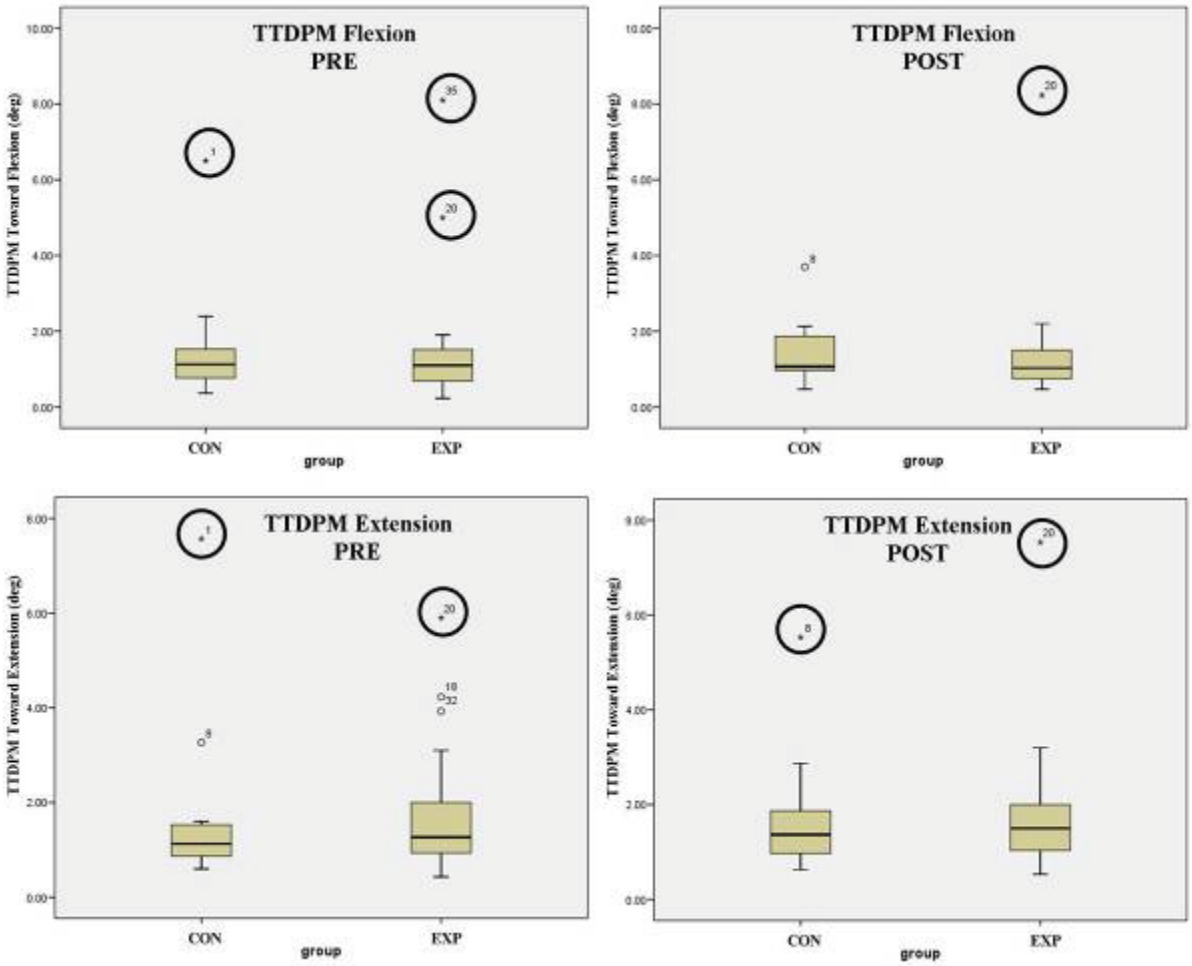


Figure 25. Stem-and-leaf Plot and Outliers on TTDPM Flexion and Extension (PRE and POST)

After removing the extreme outliers, mean proprioception data are presented in Table 8. The ANOVA revealed that there were no significant training effects on knee TTDPM toward flexion ($F(1,30) = 1.096$, $p = 0.304$) or knee TTDPM toward extension ($F(1,30) = 1.782$, $p = 0.192$).

Table 8. Proprioception: TTDPM

		CON		EXP		
		MEAN	SD	MEAN	SD	p
TTDPM Toward Flexion (degree)	Pre	1.06	0.57	1.04	0.47	0.304
	Post	1.27	0.56	1.08	0.45	
TTDPM Toward Extension (degree)	Pre	1.06	0.33	1.56	0.99	0.192
	Post	1.36	0.67	1.53	0.69	

4.4 NEUROMUSCULAR AND BIOMECHANICAL CHARACTERISTICS

4.4.1 Knee and Hip Kinematics during a Single-Leg Stop-Jump

All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed. All assumptions for ANOVA were met. Mean kinematic data are presented in Table 9. The ANOVA revealed that there were no significant training effects on knee flexion angle at IC ($F(1,34) = 2.020$, $p = 0.164$), knee valgus/varus angle at IC ($F(1,34) = 0.074$, $p = 0.788$), or hip abduction/adduction angle at IC ($F(1,32) = 0.548$, $p = 0.464$).

Table 9. Knee Flexion, Valgus/Varus, Hip Abd/Add Angles at Initial Contact during Single-Leg Stop-Jump

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Knee Flexion Angle at IC (degrees)	Pre	9.21	6.45	9.56	6.01	0.164
	Post	7.74	4.63	10.50	6.14	
Knee Valgus(-) / Varus(+) Angle at IC (degrees)	Pre	1.88	2.43	2.42	3.70	0.788
	Post	3.49	4.75	3.70	4.05	
Hip Abduction(-) / Adduction(+) Angle at IC (degrees)	Pre	-10.64	4.49	-11.91	5.43	0.464
	Post	-10.46	5.24	-10.26	5.11	

4.4.2 Knee Separation Distance during Double-Leg Drop-Jump

All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed. All assumptions for ANOVA were met. Both absolute and normalized knee separation distance data were presented in Table 10. The ANOVA revealed that there were no significant training effects on knee separation distance ($F(1,34) = 0.013$, $p = 0.910$) or normalized knee separation distance ($F(1,34) = 0.044$, $p = 0.835$).

Table 10. Knee Separation Distance at the Deepest Point of a Landing during Double-Leg Drop-Jump

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Knee Separation Distance (cm)	Pre	28.81	6.05	30.80	6.64	.910
	Post	29.27	5.74	31.15	7.34	
Knee Separation Distance Normalized	Pre	1.06	0.21	1.22	0.25	.835
	Post	1.07	0.21	1.23	0.27	

4.4.3 Knee Flexion Stiffness during a Single-Leg Stop-Jump

All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed. The normality was violated for the following as defined in Table 11: CON-PRE (Shapiro-Wilk: $W = 0.682$, $p < 0.001$) and EXP-POST (Shapiro-Wilk: $W = 0.749$, $p < 0.001$). A stem-and-leaf table from SPSS revealed that there was one extreme outlier in the control group on pre knee stiffness and one extreme outlier in the experimental group on post knee stiffness (Figure 26). After removing the outliers from the control group (#6) and from the experimental group (#21), all assumptions for ANOVA were met.

After removing extreme outliers, all knee stiffness data are presented in Table 11. A 2 × 2 mixed design analysis of variance was performed on knee stiffness as a function of group (CON, EXP) and time (PRE, POST). The ANOVA revealed that there were no significant training effects on knee stiffness ($F(1,32) = 1.973$, $p = 0.170$).

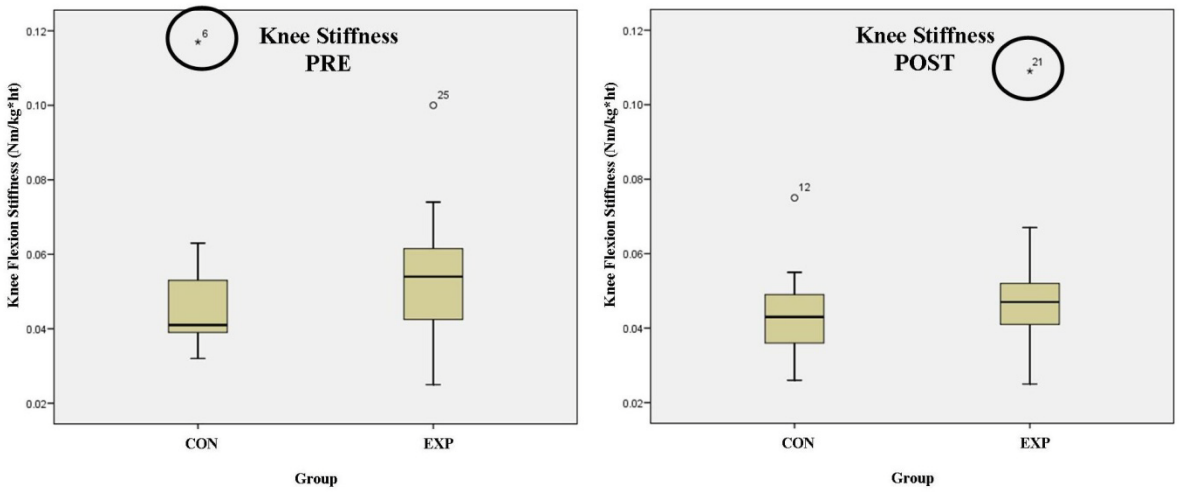


Figure 26. Stem-and-leaf Plot and Outliers on Knee Stiffness (PRE and POST)

Table 11. Knee Flexion Stiffness during a Landing Phase of Single-Leg Stop-Jump

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Knee Flexion Stiffness (Nm/kg*ht)	Pre	0.045	0.009	0.053	0.016	0.170
	Post	0.044	0.013	0.046	0.009	

4.4.4 Hamstrings/Quadriceps Muscle Activation Ratio at Pre-Landing Phase during Single-Leg Stop-Jump

All data were screened for outliers and Shapiro-Wilk tests of normality and Brown-Forsythe test of homogeneity of variance were performed. All data were positively skewed and violated the assumption of normality (Table 12). Usually, ANOVA is robust against violations of normality as long as a variable is skewed in the same direction across all cells of the design.[346] Therefore, no transformation of data was used for the analysis. A stem-and-leaf table revealed that there was one extreme outlier (figure 27). The extreme outlier was removed from the analyses.

Table 12. Shapiro-Wilk Test of Normality

		CON			EXP		
		W	df	P	W	df	P
Ham/Quad EMG Ratio at Pre-Landing Phase	Pre	0.871	13	0.05	0.848	23	0.01
	Post	0.813	13	0.01	0.754	23	0.01

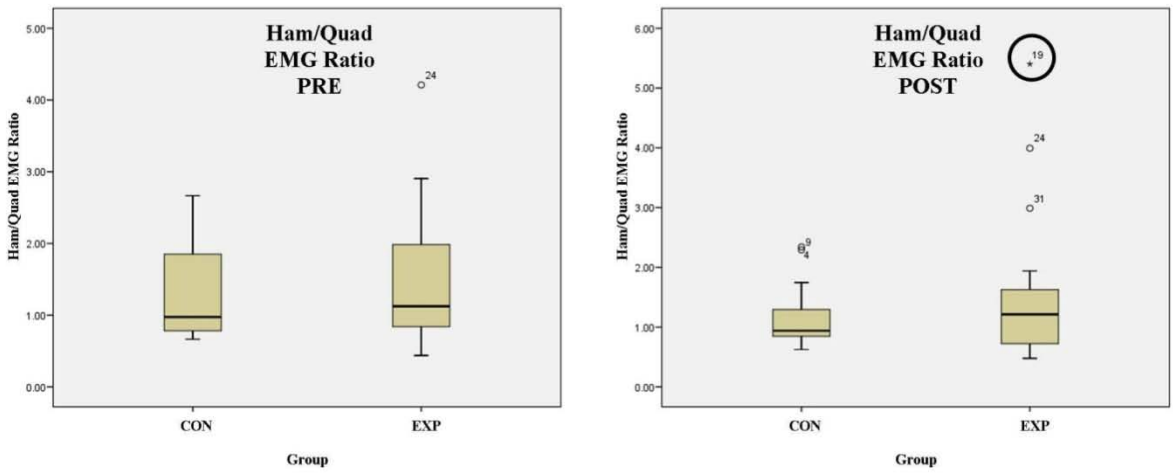


Figure 27. Stem-and-leaf Plot and Outliers on Ham/Quad EMG Ratio (PRE and POST)

After removing extreme outlier, all Ham/Quad EMG ratio data are presented in Table 13. The ANOVA revealed that there were no significant training effects on Ham/Quad EMG ratio ($F(1,33) = 0.026$, $p = 0.873$).

Table 13. Ham/Quad EMG Ratio

		CON		EXP		
		MEAN	SD	MEAN	SD	p
Ham/Quad EMG Ratio	Pre	1.36	0.68	1.43	0.91	0.873
	Post	1.21	0.57	1.32	0.85	

4.5 APFT

The control group did not perform both pre- and post-training APFT tests and the experimental group did not perform the post-training APFT. The pre-training APFT data from the experimental group are presented in Table 14.

Table 14. APFT Score

	EXP – PRE ONLY	
	MEAN	**SD**
Push-ups	**57.0**	**15.3**
Sit-ups	**65.2**	**11.3**
2 Mile Run	**15.8**	**2.1**

5.0 DISCUSSION

The purpose of this study was to evaluate the effects of an 8-week nonlinear periodized training program on physical fitness and contributors to functional knee joint stability in 101st Division Army soldiers. The contributors to functional knee joint stability were evaluated as dependent variables: knee and hip strength, the rate of force development, knee proprioception, and neuromuscular and biomechanical characteristics during dynamic movements. It was hypothesized that the nonlinear periodized training would induce favorable adaptations and that subjects in the experimental group would demonstrate significant improvements in knee strength; rate of force development and proprioception; knee flexion at landing; muscular co-contraction; and knee stiffness to absorb landing impact effectively. Despite these research hypotheses, there were no statistically significant findings for any dependent variables. Specific aims, research hypotheses, and potential confounding factors are further discussed in each section below.

5.1 CONFOUNDING FACTORS

The attrition rate of 30.8% was much higher than anticipated. Due to the deployment schedule, a majority of the soldiers' time was allocated to deployment preparation and for family time prior to this deployment. Traditionally, Army training studies have used a large number of

participants and evaluated injury and APFT scores. For example, Knapik and colleagues have evaluated the effects of a 9-week training program on over 1200 Soldiers in an experimental group and reported reduced overuse injuries, no changes in traumatic injuries, and high success rates on the fitness tests in the experimental group.[79] However, this training program was designed for new soldiers who attended basic combat training, which is a much different situation from that of the current study in which all soldiers are experienced and preparing for their deployment. In civilian studies, an attrition rate of 12-22% has been reported.[58, 66, 67]

Previous studies have also reported the minimum exposure criteria of 66-75% participation.[58, 67] In the current study, the experimental group had, on average, a 58.9% participation rate. There were only eight soldiers who participated above a 66% exposure rate. Both attrition and lack of participation are two primary confounding factors and potential reasons why no statistically significant results were found.

5.2 STRENGH

The current study did not find any significant training effects on knee flexion strength, knee extension strength, or hip abduction strength ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee extension, knee flexion, and hip abduction strength in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. The strength data in the current study were similar to previous studies, suggesting the testing procedures were properly executed.[200, 246]

Previous intervention studies have incorporated resistance or plyometric training and reported increased quadriceps and hamstring strength as well as an improved

hamstring/quadriceps strength ratio.[68, 246] Lephart and colleagues[246] reported increased quadriceps strength after an 8-week plyometric and resistance training program. This program included lateral step-downs, squat, leg curls, leg extensions, and lunges for one set of 20-30 repetitions and several jump exercises for 10 repetitions, three times a week for 8 weeks. Hewett and colleagues[68] reported an increased hamstrings/quadriceps strength ratio after a 6-week plyometric training program. This program included several jump exercises for one set of 20-30 repetitions and two lower extremity resistance exercises (leg press and calf raises) for one set of 15 repetitions three times a week. The current study included similar types of exercises and repetitions. However, one main difference from those previous studies is that the resistance workouts were performed twice a week in the current study. A position statement by the American College of Sports Medicine recommends resistance training two to three times a week for novice athletes in order to increase muscular strength.[52] Since the current study was confounded by a lack of participation and exposure, many subjects did not meet the criteria of two resistance training sessions per week on regular basis, potentially explaining the lack of significant results.

5.3 RATE OF FORCE DEVELOPMENT

The current study did not find any significant training effects on rate of force development ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee extension and flexion RFD in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. RFD data for the

MVIC normalized value in the current study were similar to a previous study, suggesting the testing procedures were properly executed.[325]

Aagaard and colleagues[325] have reported a 19% increase in RFD after 14 weeks of resistance training. This training program consists of five different resistance exercises for the lower extremity (hack squat, incline leg press, knee extension, hamstring curl, and calf raise) for 3-5 sets of 6-15 repetitions three times a week. A 16% increase in the maximum knee extensor strength after the training was reported.[325] It is apparent that a training program with heavy emphasis on resistance training could induce an adaptation to increase maximum strength as well as RFD. In the current study, a lack of training volume and duration might be a potential reason for a lack of significant findings in RFD.

Interestingly, Gruber and Gollhofer[60] reported an increase in RFD without significant changes in maximum strength after a balance-based training program. This training program consisted of unilateral balance exercises on wobble boards, spinning tops, soft mats, and two-dimensional free moving platforms for four sets of 20 seconds each leg twice a week over 4 weeks. The current study utilized a balance disc to do unilateral balance exercises and a wobble board to do landing, squatting, and lunges with eyes open and closed for one set of 30-60 seconds on each leg once a week. In addition, the current study included lunges and squats on an unstable surface for one set of 10-20 repetitions once a week. The total volume of balance activities in the current study was equivalent to the program by Gruber and Gollhofer[60]. Despite similar volume, the current training program did not induce favorable changes in RFD.

5.4 PROPRIOCEPTION

The current study did not find any significant training effects on proprioception ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee extension and flexion TTDPM in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. The TTDPM data in the current study were similar to previous studies, suggesting the testing procedures were properly executed.[347, 348]

Few studies have evaluated the effect of physical training on knee proprioception in healthy population. Previously, Thompson and colleagues[55] reported enhanced proprioception after 6 weeks of physical training in an elderly population. This resistance training program for the lower extremity included double-leg press, hamstring curls, and calf raises for three sets of 10 repetitions, three times a week. However, the subject demographics were very different from those in the current study (more specifically, average age of 69.3 vs. 24.2, respectively), making it difficult to make comparisons between the studies. Holm and colleagues[245] did not find any improvement in knee proprioception after 8 weeks of neuromuscular training in elite female handball players. The neuromuscular training consisted of five minutes of floor activities (running, cutting, planting/turning), five minutes of throwing/catching a handball on a soft mat, and five minutes of squats and bouncing/tossing a handball, performed three times a week. The current study incorporated running/cutting activities and balance activities longer than five minutes in duration in addition to two resistance training sessions a week; however, no significant changes in knee proprioception were observed. Perhaps, it might be difficult to improve TTDPM in healthy subjects without any proprioception deficits, as suggested by Holm et al.[245] Another explanation is that it might take longer than 8 weeks to see a noticeable

improvement in proprioception. Lephart et al.[348] reported that trained gymnasts scored 1.1 degrees in knee TTDPM compared with 1.9 degrees by untrained controls. Holm et al.[245] reported a score of 0.8 degrees in knee TTDPM by elite handball players. The values by trained athletes were smaller (better proprioception) than the average TTDPM values observed in the current study (1.26 degrees), suggesting that the participants in the current study might still be able to improve proprioception.

5.5 NEUROMUSCULAR AND BIOMECHANICAL CHARACTERISTICS

5.5.1 Knee and Hip Kinematics during a Single-Leg Stop-Jump

The current study did not find any significant training effects on knee or hip kinematics during a single-leg stop-jump ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee flexion and hip abduction and less valgus joint angle at initial foot contact in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. Knee flexion, valgus/varus, and hip abduction angles at initial contact were similar to a previous study, suggesting the testing procedures were properly executed.[246]

Myer and colleagues[57] reported an increase in hip abduction angle and no changes in knee valgus/varus angles after 7 weeks of either a plyometric training program or a balance training program. The plyometric training program included lower extremity jump exercises (wall jump, squat jump, tuck jump, lunge jump, broad jump, and forward jump) for 10-15 seconds, box jumps (box drop jump and lateral box jump) for 6-10 repetitions, and basic

resistance training (squat, leg curl, and hang clean) for 1-2 sets of 8-20 repetitions, performed three times a week.[57] An increase in knee flexion angle at initial contact was reported only after the plyometric training, not after the balance training.[57] Similarly, Lephart and colleagues[246] reported an increase in knee flexion and hip flexion after neuromuscular training. The neuromuscular training program consisted of resistance training (squats, leg curls, leg extensions, and abdominal curls), single-leg balance, and several jump exercises, performed three times a week for eight weeks.[246] However, no changes in knee valgus/varus and hip abduction angles were observed.[246] Chappell and colleagues[349] reported an increase in knee flexion angle after 6-week of neuromuscular training; however, no changes in knee valgus/varus and hip abduction angles at initial contact during a drop-jump task were observed. The neuromuscular training program consisted of abdominal crunches, lunges, single-leg balance, agility, and jumping task for 20 repetitions/jumps six days a week.[349] Each training session lasted only 10-15 minutes; however, the subjects executed all of the training exercises in every practice sessions.[349] Those studies support that plyometric exercises are included a few times a week to see an adaptation in knee flexion angles.[57, 246, 349]

Another potential reason of a lack of significant findings might be due to the lack of video feedback. A previous study reported that landing techniques were improved quickly by providing athletes with video feedback.[350] Herman and colleagues[351] applied this feedback concept and combined it with a 9-week strength training program and reported that knee flexion, hip flexion, and hip abduction angles during a stop-jump task were increased. The current training program focused on instructions as a means of feedback and teaching proper landing technique rather than using video feedback.

5.5.2 Knee Separation Distance during Double-Leg Drop-Jump

The current study did not find any significant training effects on knee separation distance during a double-leg drop-jump ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee separation distance in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. Knee separation distance during double-leg drop-jump was similar to a previous study, suggesting the testing procedures were properly executed.[319]

Noyes and colleagues[318] evaluated the effects of a 6-week neuromuscular training in female athletes and reported a 6 cm increases in the knee separation distance. The training program consisted of general stretching exercises for 3 sets of 30 seconds, resistance exercises for 1 set of 15 repetitions (abdominal curls, back hyperextensions, leg press, and calf raises), and several jumping exercises (wall jumps, tuck jumps, broad jumps, squat jumps, bounding, and stick landing) for 10-30 seconds, performed three times a week.[241] As previously stated, the current study executed only one plyometric session per week. A lack of frequency of plyometric training sessions might explain a lack of significant finding in the current study.

Another possible explanation is the difference in subject demographics. Subjects in the study by Noyes et al.[318] were junior-high school male and female athletes, aged 11-19 years old. A marked decrease in knee separation distance (more valgus position) from pre-landing phase to take-off phase (near maximum knee flexion) was reported in most subjects (72-80%). The current study used only male soldiers, aged 19-38 years old. When the same variable was evaluated in the current study, a decrease in knee separation distance was observed in only 40% of the subjects. For those who already had proper landing technique (alignment of the knee over

the toe) during the landing phase of a drop-jump task, we anticipate minimal changes in their landing technique after the training.

5.5.3 Knee Flexion Stiffness during a Single-Leg Stop-Jump

The current study did not find any significant training effects on knee flexion stiffness during a single-leg stop-jump ($p > 0.05$). It was hypothesized that there would be a greater improvement in knee flexion stiffness in the experimental group than in the control group as reflected by a significant group by time interaction. This research hypothesis was rejected. Knee flexion stiffness was similar to a previous report, suggesting the testing procedures were properly executed.[191]

To my knowledge, no studies have evaluated the effects of training on knee joint stiffness. Joint stiffness can be influenced by several factors: muscle activation, joint geometry, and muscular strength.[190, 194-196, 198] Because the current study did not show significant changes in those modifiable factors, it was less likely to have a significant change in joint stiffness. A lack of research in the area of training effects on joint stiffness makes it difficult to explain the current findings in more detail.

5.5.4 Hamstrings/Quadriceps Muscle Activation Ratio at Pre-Landing Phase during Single-Leg Stop-Jump

The current study did not find any significant training effects on co-contraction ratio ($p > 0.05$). It was hypothesized that there would be a greater co-contraction ratio in the experimental group than in the control group as reflected by a significant group by time interaction. This

research hypothesis was rejected. The co-contraction ratio in the current study was much higher than what has been previously reported.[312]

In the current study, the co-contraction ratio was, on average, a 1.21-1.43 ratio. Besier and colleagues[312] used a similar methodology as in the current dissertation, and reported a 0.6-0.7 hamstrings/quadriceps ratio during the 50ms pre-contact phase during sidesteps and crossover cut maneuvers. One reason for the difference may be the time duration chosen for the pre-contact phase. During data analyses, it was generally observed that the quadriceps muscles had minimal activity during the first 100-150ms prior to initial contact, but increased greatly in last 50ms prior to initial contact. A previous study reported earlier onset of the quadriceps and higher amplitude of EMG prior to foot contact with a tall box drop-landing compared with a small box drop-landing.[26] The single-leg stop-jump task in the current study might not have had enough intensity to see greater quadriceps muscle pre-activation at early onset of 100-150ms prior to the initial contact.

Few studies have evaluated the training effects on co-contraction ratio. Previously, increases in mean EMG amplitude, the rate of EMG development, and integrated EMG were reported as an adaptation to resistance training and neuromuscular training.[246, 325] Hurd and colleagues[62] demonstrated increased integrated EMG of the hamstrings muscles after perturbation training, but did not show any significant changes in the hamstrings/quadriceps co-contraction ratio. The perturbation training consisted of standing/balancing on unstable platforms for 2-3 sets of 1 minute while a training coach perturbed the balancing board/platform, for a total of 10 sessions over a 3-4 week periods.

5.6 APFT

The APFT results were incomplete; therefore, the research hypothesis could not be evaluated. Several studies have reported low fitness level as measured by APFT as a risk factor for common musculoskeletal injuries.[2, 8-13] Jones and colleagues identified that soldiers with 24 push-ups or lower had a relative risk of injury of 2.0-3.2 and those with a 2 mile run time slower than 15.7 minutes had a relative risk of injury of 1.6-2.1. The current APFT results in the experimental group showed that, on average, soldiers had good push-ups fitness (57.0 repetitions), but a slightly poor 2 mile run time (15.8 min).

5.7 CONCLUSION

The current study did not induce the hypothesized changes in the contributors of functional knee joint stability and physical fitness in the experimental group. There were two major confounding factors: high attrition rate and low training exposure. Those confounding factors limit the current research and soldiers did not have enough stimuli to see favorable adaptations in their physical fitness and contributors of functional knee joint stability.

A future study should address those confounding factors by understanding a deployment and training cycle and by avoiding holidays. It is important to get a buy-in from both soldiers and their commanders. Recruiting a larger number of subjects is also important to account for attrition. A future study should monitor both control and experimental groups on the daily training exposure and types of training.

A future study should also consider including plyometric exercises and feedback on landing techniques at least twice a week to induce favourable adaptations on landing kinematics. An Army Physical Fitness Test must be included in a future study to evaluate the effects of the current training program on physical fitness.

APPENDIX A

WORKOUT SHEETS: WEEKLY EXERCISE LIST

DAY 1 WORKOUT

DATE: 9/1/08

20 MINUTE WARM UP PERIOD

4 x 300 YD SHUTTLE

GOAL - 1:05-1:30MIN. REST - 3:00MIN

VOLUME - 1200 YDS

4 CONE DRILL - 20 YARDS

SPRINT - SHUFFLE - BACKPEDAL - SHUFFLE

BACKPEDAL-SHUFFLE-SPRINT-SHUFFLE

SPRINT-CARIOCA-BACKPEDAL-CARIOCA

BACKPEDAL-CARIOCA-SPRINT-CARIOCA

CONE HOPS - 6 INCH

2 FEET - SIDE TO SIDE - 2 X 20 SEC

AGILITY LADDER - 15 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X4

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 9/2/08

20 MINUTE WARM UP PERIOD

1	REDCORD SQUAT	2 X 12
2	REDCORD LUNGE (R&L)	1 X 12
3	REDCORD SIDE PLANK-ADDUCTION (R&L)	1 X 30 SEC
4	REDCORD SIDE PLANK-ABDUCTION (R&L)	1 X 30 SEC
5	REDCORD 2 LEG CALF RAISE	1 X 12
6	DUMBBELL or SANDBAG UPRIGHT ROW	2 X 12
7	VERSA TUBE INTERNAL ROTATION (R&L)	1 X 12
8	VERSA TUBE EXTERNAL ROTATION (R&L)	1 X 12
9	MANUAL RESISTANCE PUSH UP	1 X 12, 1 X 10
10	DUMBBELL or SANDBAG BENT OVER ROW	2 X 12
11	DUMBBELL/SANDBAG SEATED SHOULDER PRESS	2 X 12

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 9/3/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 MIN = 1000 METER X 4

16:31MIN AND GREATER = 800 METER X 4

REST = 5 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 9/4/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	1 X 12, 1 X 10
2	DUMBBELL or SANDBAG ROMAINIAN DEAD LIFT	1 X 12, 1 X 10
3	DUMBBELL or SANDBAG HIGH PULL	1 X10, 1 X 8
4	HANG CLEAN TECHNIQUE with BAR	
5	DUMBBELL or SANDBAG HANG CLEAN	2 X 8
6	DUMBBELL or SANDBAG PUSH PRESS	1 X 10, 1 X 8
7	VERTICAL JUMPS	2 X 10
8	TUCK JUMPS	2 X 10
9	BOX JUMP - FWD - (2 FEET) SOFT LANDING	2 X 8
10	PUSH UP w/CLAP	2 X MAX
11	MEDICINE BALL PULLOVER PASS (LYING ON BACK)	1 X 10, 1 X 8
12	MEDICINE BALL STANDING CHEST PASS	1 X 10, 1 X 8
13	MEDICINE BALL SIT UP	2 X 30 SEC
14	MEDICINE BALL TRUNK ROTATION (R&L)	1 X 30 SEC

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 9/5/08

20 MINUTE WARM UP PERIOD

DISTANCE RUN: 2 MILE, 1.5 MILE, 1 MILE TWO TIMES

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

14:30 MIN OR BETTER = 2 MILE X 2

14:31 - 16:30 = 1.5 MILE X 2

16:31AND GREATER = 1 MILE x 2

REST = 5 MINUTES

		REPS
1	STICK MASSAGE - CALF	30 SEC @ SIDE
2	STICK MASSAGE - TIBIALIS ANTERIOR	30 SEC @ SIDE
3	STICK MASSAGE - QUADS	30 SEC @ SIDE
4	STICK MASSAGE - HAMSTRINGS	30 SEC @ SIDE
5	STICK MASSAGE - IT BAND	30 SEC @ SIDE
6	FOAM ROLLER - IT BAND	30 SEC @ SIDE
7	CAT & COW & FIND NEUTRAL POSITION	60 SEC
8	QUADRIPED w/ARMS	60 SEC
9	QUADRIPED w/LEGS	60 SEC
10	QUADRIPED w/ARMS & LEGS	60 SEC
11	DEAD BUG (PELVIC TILT)	60 SEC
12	DEAD BUG w/ARMS	60 SEC
13	DEAD BUG w/LEGS	60 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 9/8/08

20 MINUTE WARM UP PERIOD

4 x 300 YD SHUTTLE

GOAL - 1:05-1:30MIN. REST - 3:00MIN

VOLUME - 1200 YDS

4 CONE DRILL - 20 YARDS

SPRINT - SHUFFLE - BACKPEDAL - SHUFFLE

BACKPEDAL-SHUFFLE-SRINT-SHUFFLE

SPRINT-CARIOCA-BACKPEDAL-CARIOCA

BACKPEDAL-CARIOCA-SPRINT-CARIOCA

CONE HOPS - 6 INCH

2 FEET - SIDE TO SIDE - 2 X 20 SEC

AGILITY LADDER - 15 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X4

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 9/9/08

20 MINUTE WARM UP PERIOD

1	90 DEGREE WALL SIT	2 x 60 sec
2	MANUAL RESISTANCE HAMSTRING CURL	1 x 12
3	DUMBBELL 1 LEG SQUAT (R&L)	1 x 12
4	MANUAL RESISTANCE HIP ADDUCTION (R&L)	1 x 12
5	DUMBBELL CALF RAISE 1 LEG @ TIME (R&L)	1 x 12
6	MANUAL RESISTANCE REVERSE CRUNCH	1 x 20
7	DUMBBELL or PLATE GOOD MORNINGS	1 x 12
8	MANUAL RESISTANCE 4-WAY NECK	1 X 12
9	REDCORD PUSH UP	2 x 10
10	REDCORD 45 DEGREE PULL UP	2 x 10
11	REDCORD KNEELING LATERAL SHOULDER RAISE (R&L)	1 x 10
12	REDCORD KNEELING FRONT SHOULDER RAISE	1 x 12
13	REDCORD SEATED REVERSE FLY	2 x 12
14	REDCORD SEATED DIPS	1 x 12
15	MANUAL RESISTANCE LYING BICEPS CURL-BAR	1 X 12

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 9/10/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 MIN = 1000 METER X 4

16:31MIN AND GREATER = 800 METER X 4

REST = 5 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 9/11/08

20 MINUTE WARM UP PERIOD

1	HANG CLEAN TECHNIQUE with BAR	
2	DUMBBELL or SANDBAG HANG CLEAN	2 X 8
3	DUMBBELL or SANDBAG PUSH PRESS	2 X 8
4	DUMBBELL or SANDBAG FARMERS WALK	2 X 40 YDS
5	LATERAL HOPS (R&L)	2 X 10
6	MEDICINE BALL PUSH UP	2 X MAX
7	MEDICINE BALL SEATED SIDE THROW (R&L)	2 X 10
8	MEDICINE BALL SIT UP	2 X 30 SEC
9	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 9/12/08

10 MINUTE WARM UP AND STRETCH

4 MILE ROAD MARCH - NO RUNNING

GOAL - UNDER 60 MINUTES

ANKLE STRENGTHENING

BDE Run

DORSI FLEXION - 1 X 15

INVERSION - 1 X 15

EVERSION - 1 X15

TOWEL ACHILLES TENDEON STRENTCH - 1 X 30 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 9/15/08

20 MINUTE WARM UP PERIOD

5 x 200 YD SHUTTLE

GOAL - 45-60SEC REST - 2:00MIN

VOLUME - 1000 YDS

3 CONE DRILL (TRIANGLE) - 24 YARDS

R&L-SPRINT-SHUFFLE-BACKPEDAL

R&L-BACKPEDAL-SHUFFLE-SPRINT

R&L-SPRINT-CARIOCA-BACKPEDAL

R&L-BACKPEDAL-CARIOCA-SPRINT

HOPS/JUMPS

6" CONE HOPS - 2 FEET - SIDE/SIDE - 30 SEC X 2

6" CONE HOPS - 1 FOOT(L&R) - SIDE/SIDE - 20 SEC X 1

JUMP ROPE - 2 FEET - 30 SEC X 2

JUMP ROPE - 1 FOOT(L&R) - 20 SEC X 1

AGILITY LADDER - 15 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE X 2

SIDE RIGHT IN X 1

SIDE LEFT IN X 1

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 9/16/08

20 MINUTE WARM UP PERIOD

1	REDCORD SQUAT	2 X 12
2	REDCORD LUNGE (R&L)	1 X 12
3	REDCORD SIDE PLANK-ADDUCTION (R&L)	1 X 45 SEC
4	REDCORD SIDE PLANK-ABDUCTION (R&L)	1 X 45 SEC
5	REDCORD ABDOMINAL CRUNCH	1 X 25
6	REDCORD LOW BACK EXTENSION	1 X 15
7	DUMBBELL or SANDBAG UPRIGHT ROW	1 X 10, 1 X 8
8	VERSA TUBE INTERNAL ROTATION (R&L)	1 X 12
9	VERSA TUBE EXTERNAL ROTATION (R&L)	1 X 12
10	PUSH UP	MAX - 45 SEC
11	DUMBBELL or SANDBAG BENT OVER ROW	2 X 8
12	DUMBBELL or SANDBAG SEATED SHOULDER PRESS	2 X 8

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 9/17/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 5 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 9/18/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	1 X 10, 1 X 8
2	DUMBBELL or SANDBAG ROMAINIAN DEAD LIFT	1 X 10, 1 X 8
3	HANG CLEAN TECHNIQUE with BAR	
4	DUMBBELL or SANDBAG HANG CLEAN	2 X 8
5	DUMBBELL or SANDBAG PUSH PRESS	2 X 8
6	TUCK JUMPS	2 X 8
7	BOX JUMP - FWD - (2 FEET) SOFT LANDING	2 X 8
8	PUSH UP w/CLAP	2 X 20 SEC
9	MEDICINE BALL PULLOVER PASS (LYING ON BACK)	1 X 10, 1 X 8
10	MEDICINE BALL SEATED TWIST	2 X 30 SEC
11	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 9/19/08

20 MINUTE WARM UP PERIOD

DISTANCE RUN: 2 MILE, 1.5 MILE, 1 MILE TWO TIMES

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

14:30 MIN OR BETTER = 2 MILE X 2

14:31 - 16:30 = 1.5 MILE X 2

16:31AND GREATER = 1 MILE x 2

REST = 5 MINUTES

		REPS
1	STICK MASSAGE - CALF	30 SEC @ SIDE
2	STICK MASSAGE - TIBIALIS ANTERIOR	30 SEC @ SIDE
3	STICK MASSAGE - QUADS	30 SEC @ SIDE
4	STICK MASSAGE - HAMSTRINGS	30 SEC @ SIDE
5	STICK MASSAGE - IT BAND	30 SEC @ SIDE
6	FOAM ROLLER - IT BAND	30 SEC @ SIDE
7	CAT & COW & FIND NEUTRAL POSITION	60 SEC
8	QUADRIPED w/ARMS	60 SEC
9	QUADRIPED w/LEGS	60 SEC
10	QUADRIPED w/ARMS & LEGS	60 SEC
11	DEAD BUG (PELVIC TILT)	60 SEC
12	DEAD BUG w/ARMS	60 SEC
13	DEAD BUG w/LEGS	60 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 9/22/08

20 MINUTE WARM UP PERIOD

6 x 150 YD SHUTTLE

GOAL - 35-45SEC 1:20 min. REST

VOLUME - 900 YDS

T - CONE DRILL- 30 YARDS

SPRINT - SHUFFLE - BACKPEDAL

BACKPEDAL - SHUFFLE - SPRINT

SPRINT - CARIOCA - BACKPEDAL

BACKPEDAL - CARIOCA - SPRINT

HOPS/JUMPS

JUMP ROPE - 2 FEET - 40 SEC X 1

JUMP ROPE - 1 FOOT(L&R) - 20 SEC X 1

AGILITY LADDER - 30 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE (FORWARD) X 2

SCISSORS X 2

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 9/23/08

	20 MINUTE WARM UP PERIOD	
1	90 DEGREE WALL SIT	2 x 60 sec
2	MANUAL RESISTANCE HAMSTRING CURL	1 x 12
3	DUMBBELL 1 LEG SQUAT (R&L)	1 x 12
4	MANUAL RESISTANCE HIP ADDUCTION (R&L)	1 x 12
5	DUMBBELL CALF RAISE 1 LEG @ TIME (R&L)	1 x 12
6	MANUAL RESISTANCE REVERSE CRUNCH	1 x 20
7	DUMBBELL or PLATE GOOD MORNINGS	1 x 12
8	REDCORD PUSH UP	2 x 10
9	REDCORD 45 DEGREE PULL UP	2 x 10
10	REDCORD KNEELING LATERAL SHOULDER RAISE (R&L)	1 x 10
11	REDCORD KNEELING FRONT SHOULDER RAISE	1 x 12
12	REDCORD SEATED REVERSE FLY	2 x 12
13	REDCORD SEATED DIPS	1 x 12
14	MANUAL RESISTANCE LYING BICEPS CURL-BAR	1 X 12
	10 MINUTE STRETCH PERIOD	

DAY 3 WORKOUT

DATE: 9/24/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 4:30 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 9/25/08

	20 MINUTE WARM UP PERIOD	
1	DUMBBELL or SANDBAG FRONT SQUAT	1 X 10, 1 X 8
2	DUMBBELL or SANDBAG ROMAINIAN DEAD LIFT	1 X 10, 1 X 8
3	DUMBBELL or SANDBAG PUSH PRESS	1 X 10, 1 X 8
4	DUMBBELL or SANDBAG FARMERS WALK	2 X 40 YARDS
5	LATERAL HOPS (R&L)	2 X 10
6	PUSH UP - TIMED	2 X 30 SEC
7	SIT UP - TIMED	2 X 30 SEC
8	MEDICINE BALL TRUNK ROTATION (R&L)	1 X 30 SEC
9	MANUAL RESISTANCE 4-WAY NECK	1 X 12
10	10 MINUTE STRETCH PERIOD	

DAY 5 WORKOUT

DATE: 9/26/08

10 MINUTE WARM UP AND STRETCH

4 MILE ROAD MARCH - NO RUNNING

GOAL - UNDER 60 MINUTES

ANKLE STRENGTHENING

DORSI FLEXION - 1 X 15

INVERSION - 1 X 15

EVERSION - 1 X15

TOWEL ACHILLES TENDEON STRENTCH - 1 X 30 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 9/29/08

20 MINUTE WARM UP PERIOD

8 x 100 YD SHUTTLE

GOAL - 20-25 SEC 1:05 min. REST

VOLUME - 800 YDS

4 CONE DRILL (T) - 30 YARDS

R-SHUFFLE-SPRINT-BACKPEDAL-SPRINT-SHUFFLE

L-SHUFFLE-SPRINT-BAKPEDAL-SPRINT-SHUFFLE

R-CARIOCA-SPRINT-BACKPEDAL-SPRINT-CARIOCA

L-CARIOCA-SPRINT-BACKPEDAL-SPRINT-CARIOCA

HOPS/JUMPS

JUMP ROPE - 2 FEET - 40 SEC X 2

JUMP ROPE - 1 FOOT(L&R) - 20 SEC X 1

AGILITY LADDER - 30 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE (FORWARD) X 2

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 9/30/08

20 MINUTE WARM UP PERIOD

1	REDCORD BALANCE SQUAT	2 x 60 sec
2	REDCORD 1 LEG CLIMB UP (R&L)	1 x 12
3	REDCORD SIDE PLANK - ADDUCTION (R&L)	1 X 45 SEC
4	REDCORD SIDE PLANK - ABDUCTION (R&L)	1 X 45 SEC
5	REDCORD PLANK	1 X 60 SEC
6	REDCORD REVERSE PLANK	1 X 60 SEC
7	DUMBBELL or SANDBAG SHOULDER SHRUG	2 X 10
8	VERSA TUBE INTERNAL ROTATION (R&L)	1 X 12
9	VERSA TUBE EXTERNAL ROTATION (R&L)	1 X 12
10	MANUAL RESISTANCE BENCH PRESS	2 X 10
11	MANUAL RESISTANCE PULLUP w/BAR	2 X 10
12	DUMBBELL or SANDBAG SEATED SHOULDER PRESS	2 X 8

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 10/1/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 4:30 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 10/2/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	3 X 8
2	DUMBBELL or SANDBAG ROMAINIAN DEAD LIFT	1 X 10, 1 X 8
3	DUMBBELL or SANDBAG PUSH PRESS	3 X 8
4	BOX JUMP - FWD - (2 FEET) SOFT LANDING	3 X 6
5	MEDICINE BALL PULLOVER PASS (LYING ON BACK)	1 X 10, 1 X 8
6	MEDICINE BALL 1 ARM PUSH UP (L&R)	1 X 15
7	MEDICINE BALL PARTNER SIT UP	2 X 30 SEC
8	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 10/3/08

20 MINUTE WARM UP PERIOD

DISTANCE RUN: 2 MILE, 1.5 MILE, 1 MILE TWO TIMES

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

14:30 MIN OR BETTER = 2 MILE X 2

14:31 - 16:30 = 1.5 MILE X 2

16:31AND GREATER = 1 MILE x 2

REST = 5 MINUTES

1	STICK MASSAGE - QUADS	1 X 30 SEC @ SIDE
2	STICK MASSAGE - HAMSTRINGS	1 X 30 SEC @ SIDE
3	QUADRIPED w/ARMS-KNEES ON FOAM ROLLER	1 X 60 SEC
4	QUADRIPED w/LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
5	QUADRIPED w/ARMS & LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
6	DEAD BUG w/ARMS-KNEES ON FOAM ROLLERS	1 X 60 SEC
7	DEAD BUG w/LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
8	DEAD BUG w/ARMS & LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 10/6/08

20 MINUTE WARM UP PERIOD

10 x 50 YD SHUTTLE

GOAL - 8-12 SEC 50 SEC REST

VOLUME - 500 YDS

AGILITY LADDER - 30 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE (FORWARD) X 2

SCISSORS X 2

AGILITY

DOT DRILL: 2-1-2: 1 X 20 SEC

DOT DRILL: 2-1-2 w180* TURN: 1 X 20 SEC

DOT DRILL: FIGURE 8: 1 X 20 SEC

DOT DRILL: MC HAMMER: 2 X 20SEC

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 10/7/08

20 MINUTE WARM UP PERIOD

1	90 DEGREE WALL SIT	2 x 60 sec
2	MANUAL RESISTANCE HAMSTRING CURL	1 x 12
3	DUMBBELL or SANDBAG LUNGE (R&L)	2 X 10
4	MANUAL RESISTANCE HIP FLEXION (R&L)	1 x 12
5	DUMBBELL CALF RAISE 1 LEG @ TIME (R&L)	1 x 12
6	MANUAL RESISTANCE REVERSE CRUNCH	1 x 20
7	DUMBBELL or PLATE GOOD MORNINGS	1 x 12
8	REDCORD PUSH UP	2 x 10
9	REDCORD 45 DEGREE PULL UP	2 x 10
10	REDCORD KNEELING LATERAL SHOULDER RAISE (R&L)	1 x 10
11	REDCORD KNEELING FRONT SHOULDER RAISE	1 x 12
12	REDCORD SEATED DIPS	2 x 12

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 10/8/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 4:30 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 10/9/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	3 x 8
2	DUMBBELL or SANDBAG PUSH PRESS	3 x 8
3	DUMBBELL or SANDBAG WALKING LUNGE	2 X 40 YDS
4	TUCK JUMPS	3 X 6
5	PUSH UP - TIMED	2 X 30 SEC
6	SIT UP - TIMED	2 X 30 SEC
7	MEDICINE BALL SEATED TWIST	2 X 30 SEC
8	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 10/10/08

10 MINUTE WARM UP AND STRETCH

4 MILE ROAD MARCH - NO RUNNING

GOAL - UNDER 60 MINUTES

ANKLE STRENGTHENING

DORSI FLEXION - 1 X 15

INVERSION - 1 X 15

EVERSION - 1 X15

TOWEL ACHILLES TENDEON STRENTCH - 1 X 30 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 10/13/08

20 MINUTE WARM UP PERIOD

10 x 50 YD SHUTTLE

GOAL - 8-12 SEC 50 SEC REST

VOLUME - 500 YDS

AGILITY LADDER - 30 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE (FORWARD) X2

SCISSORS X 2

AGILITY

DOT DRILL: 2-1-2: 1 X 20 SEC

DOT DRILL: 2-1-2 w180* TURN: 1 X 20 SEC

DOT DRILL: FIGURE 8: 1 X 20 SEC

DOT DRILL: MC HAMMER: 2 X 20SEC

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 10/14/08

20 MINUTE WARM UP PERIOD

1	90 DEGREE WALL SIT	2 x 60 sec
2	MANUAL RESISTANCE HAMSTRING CURL	1 x 12
3	DUMBBELL or SANDBAG LUNGE (R&L)	2 X 10
4	MANUAL RESISTANCE HIP FLEXION (R&L)	1 x 12
5	DUMBBELL CALF RAISE 1 LEG @ TIME (R&L)	1 x 12
6	MANUAL RESISTANCE REVERSE CRUNCH	1 x 20
7	DUMBBELL or PLATE GOOD MORNINGS	1 x 12
8	REDCORD PUSH UP	2 x 10
9	REDCORD 45 DEGREE PULL UP	2 x 10
10	REDCORD KNEELING LATERAL SHOULDER RAISE (R&L)	1 x 10
11	REDCORD KNEELING FRONT SHOULDER RAISE	1 x 12
12	REDCORD SEATED DIPS	2 x 12

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 10/15/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 4:30 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 10/16/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	3 x 8
2	DUMBBELL or SANDBAG PUSH PRESS	3 x 8
3	DUMBBELL or SANDBAG WALKING LUNGE	2 X 40 YDS
4	TUCK JUMPS	3 X 6
5	PUSH UP - TIMED	2 X 30 SEC
6	SIT UP - TIMED	2 X 30 SEC
7	MEDICINE BALL SEATED TWIST	2 X 30 SEC
8	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 10/17/08

20 MINUTE WARM UP PERIOD

DISTANCE RUN: 2 MILE, 1.5 MILE, 1 MILE TWO TIMES

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

14:30 MIN OR BETTER = 2 MILE X 2

14:31 - 16:30 = 1.5 MILE X 2

16:31AND GREATER = 1 MILE x 2

REST = 5 MINUTES

1	STICK MASSAGE - QUADS	1 X 30 SEC @ SIDE
2	STICK MASSAGE - HAMSTRINGS	1 X 30 SEC @ SIDE
3	QUADRIPED w/ARMS-KNEES ON FOAM ROLLER	1 X 60 SEC
4	QUADRIPED w/LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
5	QUADRIPED w/ARMS & LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
6	DEAD BUG w/ARMS-KNEES ON FOAM ROLLERS	1 X 60 SEC
7	DEAD BUG w/LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC
8	DEAD BUG w/ARMS & LEGS-KNEES ON FOAM ROLLER	1 X 60 SEC

10 MINUTE STRETCH PERIOD

DAY 1 WORKOUT

DATE: 10/20/08

20 MINUTE WARM UP PERIOD

30 YD SHORT SHUTTLE

2 SETS OF 8

REST: REPS = 30 SEC, SETS = 3:00 MIN

VOLUME - 480 YDS

5 X PRO AGILITY - 20 YDS

REST = 30 SEC

VOLUME - 100 YDS

10 MINUTE STRETCH PERIOD

AGILITY LADDER - 30 FEET

1 FOOT/HOLE X 2

2 FEET/HOLE X 2

ICKY SHUFFLE X 2

IN/OUT SHUFFLE (FORWARD) X 2

SCISSORS X 2

AGILITY

DOT DRILL: 2-1-2: 1 X 20 SEC

DOT DRILL: 2-1-2 w180* TURN: 1 X 20 SEC

DOT DRILL: FIGURE 8: 1 X 20 SEC

10 MINUTE STRETCH PERIOD

DAY 2 WORKOUT

DATE: 10/21/08

20 MINUTE WARM UP PERIOD

1	90 DEGREE WALL SIT	2 x 60 sec
2	MANUAL RESISTANCE HAMSTRING CURL	1 x 12
3	DUMBBELL or SANDBAG LUNGE (R&L)	2 X 10
4	MANUAL RESISTANCE HIP ADDUCTION (R&L)	1 x 12
5	DUMBBELL CALF RAISE 1 LEG @ TIME (R&L)	1 x 12
6	MANUAL RESISTANCE REVERSE CRUNCH	1 x 20
7	DUMBBELL or PLATE GOOD MORNINGS	1 x 12
8	REDCORD PUSH UP	2 x 10
9	REDCORD 45 DEGREE PULL UP	2 x 10
10	VERSA TUBE INTERNAL ROTATION (R&L)	1 X 12
11	VERSA TUBE EXTERNAL ROTATION (R&L)	1 X 12
12	REDCORD SEATED DIPS	2 x 10

10 MINUTE STRETCH PERIOD

DAY 3 WORKOUT

DATE: 10/22/08

20 MINUTE WARM UP PERIOD

TEMPO RUN: 1200 METER, 1000 METER, 800, METER

DISTANCE DEPENDANT ON APFT 2 MILE RUN TIME

INDIVIDUAL TIME GOALS FOR DISTANCE

14:30 MIN OR BETTER = 1200 METER X 4

14:31 - 16:30 = 1000 METER X 4

16:31AND GREATER = 800 METER X 4

REST = 4:30 MINUTES

10 MINUTE STRETCH PERIOD

DAY 4 WORKOUT

DATE: 10/23/08

20 MINUTE WARM UP PERIOD

1	DUMBBELL or SANDBAG FRONT SQUAT	3 x 8
2	DUMBBELL or SANDBAG PUSH PRESS	3 x 8
3	DUMBBELL or SANDBAG WALKING LUNGE	2 X 40 YDS
4	TUCK JUMPS	3 X 6
5	PUSH UP - TIMED	2 X 30 SEC
6	SIT UP - TIMED	2 X 30 SEC
7	MEDICINE BALL SEATED TWIST	2 X 30 SEC
8	MANUAL RESISTANCE 4-WAY NECK	1 X 12

10 MINUTE STRETCH PERIOD

DAY 5 WORKOUT

DATE: 10/24/08

10 MINUTE WARM UP AND STRETCH

4 MILE ROAD MARCH - NO RUNNING

GOAL: UNDER 60 MINUTES

ANKLE STRENGTHENING

DORSI FLEXION - 1 X 15

INVERSION - 1 X 15

EVERSION - 1 X15

TOWEL ACHILLES TENDEON STRENTCH - 1 X 30 SEC

10 MINUTE STRETCH PERIOD

APPENDIX B

DEMOGRAPHICS

Please fill out the following information:

Age: _____

Gender: _____

Height in Inches: _____

Weight in Pounds: _____

Unit & Brigade: _____

MOS: _____

Years of Army Experience: _____

Smoking: _____, if yes, How Many per Week? _____

Alcohol Consumption: _____, if yes, How Much per Week? _____

APPENDIX C

INVERSE DYNAMICS CALCULATION

1. Gather all the anthropometric data (height, weight, segment length, segment mass, segment center of mass, and segment radius of gyration). Segment mass, segment center of mass, and segment radius of gyration will be estimated by using a table by Winter.[342]
2. Filter all kinematic data using a Butterworth Low-Pass Filter using the following equation (1):
   - (1) $Xf^*(nT) = a0^*X^*(nT) + a1^*X^*(nT - T) + a2^*X^*(nT - 2T) + b1^*Xf^*(nT - T) + b2^*Xf^*(nT - 2T)$
   - where Xf = filtered output coordinates; X = unfiltered coordinates; nT = nth sample; (nT-T) = (n-1)th sample; (nT-2T) = (n-2)th sample; a1, a2, b1, and b2 = filter coefficients. Filter coefficients were found in the book by Winter.[342]
3. Calculate absolute joint angles and anatomical joint angles using following equations (2), (3), and (4).
   - (2) Absolute θ for each segment = arctan ((z prox – z dis) / (x prox – x dis)

- where absolute θ = absolute angle of each segment; arctan = arc tangent; z prox = z coordinate proximal side; z dis = z coordinate distal side; x prox = x coordinate proximal side; x dis = x coordinate distal side.
- (3) Ankle angle θ = (absolute θ lower leg segment) – (absolute θ foot segment) + 90º
- (4) Knee angle θ = (absolute θ thigh segment) – (absolute θ lower leg segment)
- where ankle angle θ = anatomical ankle angle (90º means neutral, >90º means dorsiflexion, and <90º means plantarflexion); knee angle θ = anatomical knee angle
- (0º means full extension).

4. Calculate linear velocity and acceleration by using equations (5) and (6), and angular velocity and acceleration by using equations (7) and (8).
   - (5) $Vx_i = (x_{i+1} - x_{i-1}) / 2\Delta t$
   - (6) $Ax_i = (Vx_{i+1} - Vx_{i-1}) / 2\Delta t$
   - (7) $\omega_i = (\theta_{i+1} - \theta_{i-1}) / 2\Delta t$
   - (8) $\alpha_i = (\omega_{i+1} - \omega_{i-1}) / 2\Delta t$
   - where Vx_i = the velocity in x direction at *i*th time; Δt is the time between adjacent samples x_{i+1} and x_i; Axi = the acceleration in x direction at *i*th time; ω_i = angular velocity at *i*th time; α_i = angular acceleration at *i*th time.
5. Calculate segment mass and center of mass of the foot, lower leg, and thigh.
6. Calculate the moment of inertia (I_o) about the center of segment mass by using the equation (9), and also calculate the moment of inertia (I) about a joint center by using the parallel-axis theorem (10).
   - (9) $I_o = m p_o^2$
   - (10) $I = I_o + mx^2$

- where Io = the moment of inertia about the center of segment mass; m = mass of segment; po^2 = the radius of gyration; x = distance between center of mass and center of rotation.

7. Calculate the reaction force at the ankle joint in the x and y direction by using equations (11) and (12) based on the Newton's 2nd Law: ∑F = MA (linear dynamic equilibrium) and ∑T = Iα (angular dynamic equilibrium)
   - (11) ∑Fx = MAx = GRFx + Fx prox
   - (12) ∑Fz = MAz = GRFz + Fz prox – mg
   - ∑Moment = ((Rxprox*Fzprox) – (Rzprox*Fxprox)) + ((Rxdis*GRFz – Rzdis*GRFx)) – (Io*α)
   - where ∑F = the sum of all forces are equal to M (mass) times A (acceleration);∑ T = the sum of all torques are equal to I (inertia about the joint) times α (angular acceleration); GRFx and GRFz = ground reaction force in x and z direction, respectively; Ax and Az = linear acceleration in x and z direction, respectively; mg = mass times gravity (9.81N/m²); Fxprox1 and Fzprox = resultant force at ankle joint in x and z direction, respectively;∑Moment = the sum of torque moment at the joint; Rxprox and Rzprox = the distance from the center of mass of the foot to proximal joint center (lateral malleolus) in x and z directions; Rxdis and Rzdis = the distance from the center of mass of the foot to the distal end (foot contact point) in x and y direction, respectively; Io = the moment of inertia about the center of segment mass; α = angular acceleration of foot segment.

8. Repeat the same calculation for the lower leg segment. Lateral malleolus will become the distal point and knee joint line will become the proximal point.

APPENDIX D

DATA SUMMARY SHEET

Pre- intervention Data Sheet

PRE	1	2	3	AVE
Knee Ext Torque (Nm/kg)				
Knee Flex Torque (Nm/kg)				
Hip ABD Torque (Nm/kg)				
Knee Ext RFD (Nm/s)				
Knee Flex RFD (Nm/s)				
Knee Ext RFD Normalized (%MVIC/s)				
Knee Flex RFD Normalized (%MVIC/s)				

PRE	1	2	3	AVE
Knee Ext TTDPM (degrees)				
Knee Flex TTDPM (degrees)				

PRE	1	2	3	AVE
Stop-Jump: Knee Flex Joint Position (degrees)				
Stop-Jump: Knee Val/Var Joint Position (degrees)				
Stop-Jump: Hip Abd/Add Joint Position (degrees)				
Stop-Jump: Knee Flex Joint Stiffness (Nm/kg*HT/deg)				
Stop-Jump: EMG Co-contraction Index (percentage)				
Drop-Jump: Knee Separation Distance (cm)				
Drop-Jump: Knee Separation Distance Normalized				

PRE	
Push-Ups (repetitions)	
Sit-Ups (repetitions)	
2 Mile Run (minutes)	

Post intervention data sheet

POST	1	2	3	AVE
Knee Ext Torque (Nm/kg)				
Knee Flex Torque (Nm/kg)				
Hip ABD Torque (Nm/kg)				
Knee Ext RFD (Nm/s)				
Knee Flex RFD (Nm/s)				
Knee Ext RFD Normalized (%MVIC/s)				
Knee Flex RFD Normalized (%MVIC/s)				

POST	1	2	3	AVE
Knee Ext TTDPM (degrees)				
Knee Flex TTDPM (degrees)				

POST	1	2	3	AVE
Stop-Jump: Knee Flex Joint Position (degrees)				
Stop-Jump: Knee Val/Var Joint Position (degrees)				
Stop-Jump: Hip Abd/Add Joint Position (degrees)				
Stop-Jump: Knee Flex Joint Stiffness (Nm/kg*HT/deg)				
Stop-Jump: EMG Co-contraction Index (percentage)				
Drop-Jump: Knee Separation Distance (cm)				
Drop-Jump: Knee Separation Distance Normalized				

POST	
Push-Ups (repetitions)	
Sit-Ups (repetitions)	
2 Mile Run (minutes)	

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