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14. ABSTRACT

This report is a summary of four phase research developing and validating the Eagle Tactical Athlete Program (ETAP). Phase 1 research identified the prevalence of musculoskeletal injuries. Phase 2 research identified suboptimal physical and physiological characteristics, implications for physical readiness, and considerations for physical training implementation. Phase 3 research developed ETAP and validated to improve injury mitigating characteristics. Phase 4 research validated ETAP to mitigate musculoskeletal injuries.

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Army 101st Airborne Division (Air Assault) Injury Prevention and Performance Optimization Research Initiative

USAMRMC/TATRC # W81XWH-06-2-0070/W81XWH-09-2-0095 / W81XWH-11-2-0097

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Table of Contents

I. Introduction

In 2003, the Department of Defense and the Armed Forces Epidemiological Board identified musculoskeletal injury prevention research as a necessary focus. Unintentional musculoskeletal and overuse injuries during tactical operations training, combat, and physical training are a principal health concern in the military given the considerable investment per Soldier. Soldiers of the 101st Airborne Division (Air Assault) have been described as tactical athletes given the functional demands of operational training and combat. Considering the vigorous demands of tactical operations training, combat, and physical training, implementation of a 101st Soldier-specific injury prevention and performance optimization training research initiative was warranted. The purpose of this multi-aim research initiative was to systematically and scientifically address the current injury prevalence to 101st Airborne Division (Air Assault) Soldiers, identify modifiable injury risk factors, and optimize physical readiness.

The 101st Airborne Division (Air Assault) Injury Prevention and Performance Optimization Program is a joint research project between the University of Pittsburgh, Department of Sports Medicine and Nutrition, and the Division Command, Division Surgeon, and Blanchfield Army Community Hospital of the US Army 101st Airborne Division (Air Assault) at Fort Campbell. This project is funded by the United States Department of Defense and is under the auspices of US Army Medical Research and Materiel Command/Telemedicine and Advanced Technology Research Center.

Research activities included performing 101st Airborne Division (Air Assault) Soldier-specific task and demand analyses for the purposes of identifying the operational and training-related tasks during which musculoskeletal injuries occur (OCT 06-JUL 07- PHASE 1). These data were used to create laboratory models to identify suboptimal biomechanical, musculoskeletal, physiological, and nutritional characteristics that increase the risk of training and tactical injuries while reducing the capacity for peak operating efficiency (JUL 07-AUG 08- PHASE 2). Based on the laboratory testing results of over 400 Soldiers, the Eagle Tactical Athlete Program (ETAP) was developed and validated (AUG 08-MAR 09-PHASE 3) for implementation into Division PT. The Instructor Certification Course (ICS) was developed to educate NCOs on the theory, performance, and implementation of ETAP to the individual Soldiers (MAR 09-JAN 13- PHASE 4).

This project has provided immediate and tangible deliverables that will continue to enhance the Soldiers' war time deployment preparation. Long term solutions for optimizing the training needs of the Soldier will be established by providing a sustained human performance optimization approach that meets the unique demands of the tactical athlete. Improvements in the biomechanical, musculoskeletal, and physiological risk factors that are known to contribute to injury will result in a reduction of unintentional, musculoskeletal and overuse injuries and optimal physical readiness of 101st Airborne Division (Air Assault) Soldiers. Ultimately, Soldiers will demonstrate improved safety and enhanced tactical readiness which will result in decreased time lost due to disability, personnel attrition, and the financial burden associated with medical expenses and disability compensation.

Award Period of Performance

This report covers research activities performed 2007-2013 (Injury Prevention and Performance Optimization in 101st Airborne Soldiers, W81XWH-06-2-0070, W81XWH-09-2-0095, W81XWH-11-2-0097).

II. Phase 1 Research Activities

Aim 1: Medical Chart Reviewed and Self-reported Injury History

To identify the current prevalence of unintentional, musculoskeletal and overuse injury of Soldiers in the Army 101st during tactical operations training

This report describes medical chart reviewed and self-reported injuries for a period of one year prior to each subject's date of survey. Medical chart reviews were available for 454 subjects. A total of 145 medical chart reviewed injuries were recorded. Injury self-reports were available for 368 subjects. A total of 103 injuries were self-reported.

Number of Injuries per Subject:

Medical chart reviewed injuries: Three hundred fifty-seven subjects (357/454, 78.6%) did not have any injuries during a one year period. The average numbers of injuries reported per subject during a one year period were 0.32. Sixty-three subjects (63/454, 13.9%) had one injury, and twenty-four subjects (24/454, 5.3%) had two injuries, during a one year period.

Self-reported injuries: Two hundred eighty-four subjects (284/368, 77.2%) did not report any injuries during a one year period. The average numbers of injuries reported per subject during a one year period were 0.28. Sixty-eight subjects (68/368, 18.5%) had one injury, and thirteen subjects (13/368, 3.5%) had two injuries, during a one year period.

Table 1: Numbers of Injuries Reported per Subject (during a one year period)

Numbers of Injuries per Subject	Medical Chart Review		Self-report	
	Number of Subjects	Relative Frequency (%)	Number of Subjects	Relative Frequency (%)
0	357	78.6	284	77.2
1	63	13.9	68	18.5
2	24	5.3	13	3.5
3	6	1.3	3	0.8
4	4	0.9	0	0.0
Total subjects	**454**	**100.0%**	**368**	**100.0%**

Anatomic Location of the Injuries:

Table 2: Anatomic Location of the Injuries (during a one year period)

Injury Anatomic Location	Medical Chart Review		Self-report	
	Number of Injuries	Percent of Injuries	Number of Injuries	Percent of Injuries
Lower Extremity	85	58.6	50	48.5
Upper Extremity	30	20.7	27	26.2
Spine	21	14.5	13	12.6
Torso	8	5.5	0	0.0
Head/Face	1	0.7	9	8.7
Unknown	0	0.0	4	3.9
Total	**145**	**100.0%**	**103**	**99.9%***

* Percents do not add up to 100.0 due to rounding

The most common location for medical chart reviewed injuries was the Lower Extremity (85/145, 58.6% of medical chart reviewed injuries). The most common location for self-reported injuries was the lower extremity (50/103, 48.5% of self-reported injuries).

Table 3: Anatomic Sub-Location of the Injuries (during a one-year period)

Injury Anatomic Location	Anatomic Sub-Location	Medical Chart Review		Self-report	
		Number of Injuries	Percent of Injuries	Number of Injuries	Percent of Injuries
Upper Extremity	Hand and Fingers	9	6.2	4	3.9
	Upper Arm	1	0.7	2	1.9
	Shoulder	11	7.6	16	15.5
	Elbow	2	1.4	2	1.9
	Wrist	7	4.8	3	2.9
Lower Extremity	Foot and Toes	13	9.0	7	6.8
	Thigh	7	4.8	2	1.9
	Lower Leg	15	10.3	14	13.6
	Hip	6	4.1	4	3.9
	Knee	20	13.8	10	9.7
	Ankle	24	16.6	13	12.6
Spine	Cervical	1	0.7	0	0.0
	Thoracic	5	3.4	3	2.9
	Lumbopelvic	14	9.7	8	7.8
	Other	1	0.7	2	1.9
Torso	Chest	5	3.4	0	0.0
	Abdomen	2	1.4	0	0.0
	Other	1	0.7	0	0.0
Head/Face	Other	1	0.7	6	5.8
	Ear	0	0.0	2	1.9
	Unknown	0	0.0	1	1.0
Unknown		0	0.0	4	3.9
Total		**145**	**100.0%**	**103**	**99.8%***

* Percents do not add up to 100.0 due to rounding

Common anatomic sub-locations for medical chart reviewed injuries were the ankle (24/145, 16.6% of medical chart reviewed injuries), knee (20/145, 13.8%), and lower leg (15/145, 10.3%). Common anatomic sub-locations for self-reported injuries were the injuries were the shoulder (16/103, 15.5% of self-reported injuries), lower leg (14/103, 13.6%), and ankle (13/103, 12.6%).

Cause of the Injuries:

Table 4: Cause of Injuries (during a one year period)

Cause of Injury	Medical Chart Review		Self-report	
	Number of Injuries	Percent of Injuries	Number of Injuries	Percent of Injuries
Running	19	13.1	21	20.4
Direct Trauma	19	13.1	13	12.6
Lifting	7	4.8	8	7.8
Fall - Other	8	5.5	8	7.8
Landing	5	3.4	7	6.8
Twist/Turn/Slip (no fall)	5	3.4	3	2.9
Marching	5	3.4	6	5.8

Crushing	0	0.0	2	1.9
Cutting	0	0.0	1	1.0
Planting	0	0.0	2	1.9
Pulling	0	0.0	4	3.9
Other	12	8.3	7	6.8
Unknown	65	44.8	21	20.4
Total	**145**	**99.8%***	**103**	**100.0%**

* Percents do not add up to 100.0 due to rounding

Running and Direct trauma were the cause of 19 medical chart reviewed injuries each (each 19/145, 13.1% of the medical chart reviewed injuries).Running was the cause of 21 self-reported injuries (21/103, 20.4% of the self-reported injuries).

Activity When Injury Occurred:

Table 5: Activity When Injury Occurred (during a one year period)

Activity	Medical Chart Review		Self-report	
	Number of Injuries	Percent of Injuries	Number of Injuries	Percent of Injuries
Recreational Activity/Sports	7	4.8	19	18.4
Physical Training	42	29.0	22	21.4
Tactical Training	10	6.9	13	12.6
Motor Vehicular Accident (MVA)	10	6.9	3	2.9
Combat	0	0.0	7	6.8
Other	16	11.0	30	29.1
Unknown	60	41.4	9	8.7
Total	**145**	**100.0%**	**103**	**99.9%***

*Percent do not add up to 100.0 due to rounding

Medical Chart Reviewed Injuries:

In case of 52 medical chart reviewed injuries (52/145, 35.9%), subjects were engaged in physical training or tactical training, when the injury occurred. In case of seven medical chart reviewed injuries (7/145, 4.8%), subjects were engaged in recreational activity/sports when the injury occurred. A common sport related to injuries in the medical charts was basketball (4 injuries, 4/7, 57.1% of Recreational activity/ sports injuries).

Self-reported Injuries:

In case of 35 self-reported injuries (35/103, 34.0%), subjects were engaged in physical training or tactical training, when the injury occurred. In case of 19 self-reported injuries (19/103, 18.4%), subjects were engaged in recreational activity/sports when the injury occurred. A common sport related to injuries in the medical charts was football (4 injuries, 4/19, 21.1% of Recreational activity/ sports injuries).

Types of Injuries:

Table 6: Types of Injuries (during a one year period)

Type of Injuries		Medical Chart Review		Self-report	
		Number of Injuries	Percent of Injuries	Number of Injuries	Percent of Injuries
Fracture	Upper Extremity	5	3.4	2	1.9
	Lower Extremity	2	1.4	5	4.9
Sprain	Upper Extremity	7	4.8	4	3.9
	Lower Extremity	21	14.5	12	11.7
	Spine	1	0.7	0	0.0
Strain	Spine	4	2.8	6	5.8
	Upper Extremity	4	2.8	7	6.8
	Lower Extremity	9	6.2	8	7.8
	Torso	2	1.4	0	0.0
Tendonitis	Lower extremity	1	0.7	2	1.9
	Upper Extremity	1	0.7	0	0.0
Dislocation/Subluxation		0	0.0	4	3.9
Periostitis		1	0.7	0	0.0
Stress Fracture		4	2.8	1	1.0
Pain/Spasm/Ache		42	29.0	4	3.9
Labral Tear		1	0.7	0	0.0
Nerve		1	0.7	1	1.0
Disc Injury		1	0.7	2	1.9
Degenerative Joint Disease		1	0.7	0	0.0
Ganglion Cyst		1	0.7	0	0.0
Contusion		8	5.5	2	1.9
Chondromalacia/Patellofemoral Pain		6	4.1	3	2.9
Bursitis		1	0.7	1	1.0
Concussion		0	0.0	6	5.8
Ear Injury		0	0.0	2	1.9
Impingement		0	0.0	2	1.9
Meniscal		0	0.0	1	1.0
Shoulder Separation		0	0.0	3	2.9
Inflammation - IT band		4	2.8	3	2.9
Inflammation - Other		1	0.7	0	0.0
Inflammation - Plantar fascia		3	2.1	3	2.9
Inflammation - Shin splints		3	2.1	3	2.9
Inflammation		1	0.7	4	3.9
Unknown		1	0.7	12	11.7
Other		8	5.5	0	0.0
Total		**145**	**100.3%***	**103**	**100.0%**

* Percents do not add up to 100.0 due to rounding

Common medical chart reviewed injuries were Pain / spasm / ache (42/145, 29.0% of medical chart reviewed injuries), Sprain (29/145, 20.0%) and Strain (19/145, 13.1%). Common self-reported injuries were Strain (21/103, 20.4% of self-reported injuries), Sprain (16/103, 15.5%) and Fracture (7/103, 6.8%). An examination of medical records for a period of one year for a sample of Soldiers from the 101st Airborne Division (Air Assault) was conducted to measure the frequency of musculoskeletal injuries, assess their impact on healthcare utilization and tactical readiness, and identify types of common musculoskeletal injuries in this population. Injuries were described and classified according to their frequency, anatomic location, activity when injury occurred and injury type. Musculoskeletal injuries were common in the sample studied (52.5 per 100 soldiers per year); of these 79.3% were potentially preventable by an injury prevention training program. The majority of musculoskeletal injuries (53.8%) affected the lower extremities. In case of 36.7% of injuries, subjects were engaged in physical or tactical training when injuries occurred. Common injury types were sprains (23.6%), strains (14.2%), and "pain" (36.8%). Overuse injuries were common (13.2%). A large proportion of injuries required radiological assessment (40.6%), physical therapy (12.3%), and pain medication (76.4%); a significant proportion (45.3%) resulted in work/duty/training limitations or profile. Musculoskeletal injuries cause significant morbidity, and impact healthcare utilization and tactical readiness in this Army Airborne Division. There is a need to implement a customized injury prevention program to reduce the occurrence of preventable musculoskeletal injuries in this population.

Musculoskeletal injuries can adversely impact performance and certain injuries are risk factors for recurrence of the injury. An analysis was conducted to compare the proportion of female and male Soldiers with a self-reported history of musculoskeletal injury, during a two year period. Proportions of subjects with injuries were compared using Fisher's exact test. A greater proportion of females reported a musculoskeletal injury compared to males (41.7% and 28.1% respectively, $p = 0.119$), though this difference was not statistically significant. A greater proportion of females than males reported a lower extremity injury (27.8%, 13.8%, $p = 0.046$) and a knee injury (11.1%, 2.7%, $p = 0.033$). There was no difference in the proportion of females and males reporting an upper extremity injury (5.6%, 7.7%, $p = 1.000$). A greater proportion of females than males reported an overuse injury (22.2%, 8.8%, $p = 0.036$). Age was not significantly different between genders ($p = 0.440$). An examination of potential injury risk factors in these subjects is necessary. There may be a need to implement a customized program to prevent recurrence of certain lower extremity and overuse injuries in female Soldiers, and to prevent an adverse impact on performance.

Self-reported data are often used in injury epidemiology. The aim of this analysis was to assess self-reported recall of unintentional musculoskeletal injuries among Soldiers in the 101st Airborne Division (Air Assault). Self-reported and medical chart-reviewed injuries among Soldiers were matched by anatomic location, side (for extremity injuries), year, and type. The injuries included in the analysis were those that had occurred during the year of survey (recent injuries), and during the preceding calendar year (old injuries). Recall was expressed as the percent of medical chart-reviewed injuries correctly recalled in the self-report. Proportions were compared using the Fisher's exact test. Overall, recall was low (10.3%). Recall was higher for severe injuries (traumatic/stress fractures, 25.0%) as compared to less severe injuries (non-fracture injuries, 9.6%), but the difference was not statistically significant ($p = 0.359$). Recall was higher for recent injuries (11.5%) as compared to old injuries (9.8%), but the difference was not statistically significant ($p = 1.000$). There is a need to further investigate factors affecting recall and strategies to improve accuracy of recall of injury data in various military populations.

Conclusions

- Most injuries occur to the lower limb and spine, therefore, injury prevention interventions should "bias" the lower quadrant vs. upper quadrant.
- Running is reported as cause of injury for a major proportion of all injuries (Table 4), physical training accounts for the activity being performed most often when injuries occur (Table 5), and pain/spasm/ache account for the most frequent types of injury (Table 6): therefore, all of these suggest overtraining/overuse syndromes represent the biggest proportion of injuries, and interventions should focus on overtraining/overuse injury prevention vs. trauma prevention
- Non-contractile tissues (e.g. ligament, bone, fascia (ITB, plantar)) collectively form the greatest proportion of tissue types injured vs. muscle strains/tendonopathies (Table 6): therefore, injury prevention interventions should focus on neuromuscular control and function of the dynamic restraints to both enhance joint stability (ligament/labral/OA/PFJinjuries) and stress-shield other non-contractile tissues (bone = stress fractures, fascia = plantar fascia/ITB, nerve) from repetitive/excessive forces.

Aim 2: Task and Demand Analyses

To perform task and demand analyses of tactical operations training in Soldiers of the Army 101st Airborne and develop protocols for Phase 2- Specific Aim 2 testing

Task analyses were performed for the purpose of identifying specific tactical and physical training activities during which musculoskeletal injuries occur. Task analyses have been completed for the upper extremity, lower extremity, and spine to identify injurious task performed by the 101st Airborne/Air Assault. Examination of the task analysis data directed the development of the laboratory tasks to be 101st Airborne Division (Air Assault)-specific for collection of biomechanical data. Based on the task analyses, laboratory biomechanical procedures were developed to simulate the daily tasks of the 101st Airborne Division (Air Assault) Soldiers.

Researchers were invited to the Joint Readiness Training Center (JRTC) - Fort Polk, LA. The purpose of their visit was to observe, quantify, and identify potentially injurious mechanisms, engaged metabolic pathways, and nutritional demands relative to daily energy balance during tactical training exercises for Soldiers of the 101st Airborne Division (Air Assault). As part of the initiative to mitigate risk factors for unintentional musculoskeletal injury and optimize force readiness, the data collected at JRTC contributes to driving empirical mechanisms for task simulation in laboratory performance testing and programming of the validated Eagle Tactical Athlete Program (ETAP).

The mobile testing allowed Soldiers to be fitted with lightweight instrumentation prior to mission preparation and perform tactical operations uninhibited. Instruments were removed at the completion of the situational training exercise and after returning to the forward operating base. Soldiers of both main and support efforts were assessed during the following situational training exercises throughout the week: “Cordon Search,” “Combat Patrol,” and “Foreign Security Forces.” Quantitative and qualitative data support the programming of the comprehensive ETAP. Analyses demonstrate at risk movement mechanics, intermittent bouts of intense activity, lengthy mission duration, substantial combat load carriage, and inadequate nutrition profiles. Mounting and dismounting vehicles demand proper jumping/landing mechanics and joint alignment to safely attenuate impacts. Soldiers were observed landing in excessive forward trunk lean with their center of mass outside the bounds of their base of support, minimal knee/hip flexion, and unevenly distributed impact absorption leading to potentially injurious joint alignment and loads. Exercises to train proper landing mechanics and plyometrics are included in ETAP to minimize risk for injury. Soldiers during the situational training exercise expend 1800 and even up to 5000 calories potentially doubling the daily recommended caloric intake as compared to the general population and parallels caloric expenditure of endurance athletes.

Bursts of sprinting and cutting on unstable rugged terrain through brush, trees, and under-developed roads/footpaths while securing team position require heightened anaerobic capacity, aerobic capacity, speed, agility, strength, flexibility, and postural control. Sprints, interval runs, agility drills, and

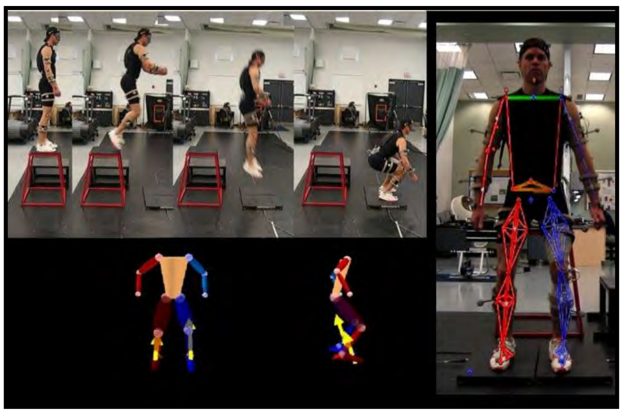
balance training built into ETAP target similar intensity and physiologic profiles. Flexibility is addressed during dynamic warm-up prior to and during cool-down after ETAP workouts.
Lifting, carrying, and dragging weapons, ammunition, body armor, equipment, and casualties require well developed whole body strength, power, and muscular endurance when encountering contact, completing med-evacs, clearing buildings, securing position, and extracting targets. Combat load carriage contributes to unintentional musculoskeletal injury and the measured combat loads during the situational training exercises ranged between 52-89 lbs. Along with the inclusion of body armor resistance training to safely prepare Soldiers in a controlled environment, ETAP incorporates sand bag workouts and exercises such as farmer carries paralleling lifting, carrying, and dragging activities experienced during tactical operation .

III. Phase 2 Research Activities

Aim 1: Laboratory Data Collection

To identify suboptimal biomechanical, musculoskeletal, physiological, tactical, and nutritional characteristics for physical readiness in Soldiers of the Army 101st

A total of 624 Soldiers (27.0 ± 6.3 years, height: 175.9 ± 8.2 cm, mass: 80.9 ± 13.8 kg) participated in this research aim to evaluate biomechanical, musculoskeletal, physiological, and nutritional characteristics. Specific testing included movement patterns during functional (tactical) tasks, musculoskeletal strength and flexibility, balance, aerobic capacity and lactate threshold, anaerobic power and capacity, body composition, nutritional history, injury history, and tactical performance.



Lower Extremity Joint Kinematic and Kinetic Data Collection

Collection of Lower Extremity Kinematic and Kinetic Data

Joint kinematic and kinetic data during the simulated physical training tasks will be calculated based on the three-dimensional coordinate data of retroreflective markers placed on the subject's torso, upper extremities, and lower extremities, anthropometric measurements of the individual subject, and the ground reaction force data. The marker set is a variation of the Helen Hayes Hospital marker set as modified by Vaughn et al. The three-dimensional coordinate data will be collected with the Peak Motus 3D Optical Capture System utilizing six high-speed optical cameras sampling at 240 Hz. Ground reaction force data will be collected using two Kistler force plates sampling at 1200 Hz. Joint centers, segmental masses, segmental centers of gravity, and segmental moments of inertia will be calculated based on the three-dimensional coordinate data and anthropometric measurements. Anatomical joint angles, linear kinematic data, and angular kinematic data will be calculated based on segmentally embedded coordinate systems utilizing Euler angles to define motion of the distal segment relative to the proximal segment. Net joint resultant forces and moments are calculated using an inverse dynamic procedure based on the ground reaction force data, body segment parameters, linear kinematics, angular kinematics, and the segmental centers of gravity. Joint kinematic and kinetic data calculations will be performed using Peak Motus 3D Gait Analysis Module (ViconPeak, Centennial, CO) based on Vaughan et al.
The high vertical drop landing is a two-legged landing from a height of 60 cm. Subjects will be asked to drop from this height onto two force plates. The one-legged stop-jump task over an obstacle involves jumping over an obstacle with one leg, landing on the force plate with the other leg, and immediately jumping forward for maximum horizontal distance. The obstacle height will be measured as 20% of the subject's height and the initial jump distance will be measured as 40% of the subject's height. Joint kinematic and kinetic data will be averaged across three trials for each leg for each task. Variables assessed include knee flexion angle, knee valgus/varus angle, knee valgus/varus moment, anterior tibia shear force, ankle inversion moment, and vertical jump height (one-legged stop-jump task).

Collection of Upper Extremity Kinematic Data

Subjects will then be fitted with electromagnetic tracking receivers used in conjunction with the Motion Monitor system to track scapular kinematics during upper extremity functional testing. Electromagnetic receivers will be placed directly over the skin of the seventh cervical vertebrae (C7), bilateral acromia, and one on the mid-shaft of each humerus. Hypoallergenic tape (The Kendall Co. Mansfield, MA) as well as double-sided adhesive disks (3M Health Care, St. Paul, MN) will secure all receivers. The acromion receivers will be affixed to the flat portion of the superior, scapular spine between the acromion angle (AA) and acromioclavicular joint (AC). The thoracic receiver will be placed on the spinous process of the seventh cervical vertebrae. Humeral receivers will be attached by means of a neoprene cuff around the upper arm at the mid-point of the humerus. The last receiver will be attached to a plastic stylus that will digitize bony landmarks on the thorax, scapula and humerus. This digitization process allows transformation of the receiver data from a global coordinate system (GCS) to an anatomically based, local coordinate system (LCS). In order to develop a LCS with respect to the GCS of the research lab, each bone/region involved for the assessment (scapula, humerus, and thorax) must have at least three anatomical points included in the digitization process. There are only two anatomical landmarks on the humerus, the medial and lateral epicondyle. In order to produce an orthogonal LCS for the humerus, the glenohumeral joint center is determined by a least square algorithm for the point of the humeral head with the least movement during several short arc movements of the humerus. Twenty short arc movements are adequate for this calculation. The glenohumeral joint center is the third anatomical landmark on the humerus and allows calculations to create a LCS for the humerus. Subjects will perform 10 repetitions of a weighted overhead pull-up task at a rate of two seconds during elevation and two seconds during lowering (Figure 2). A weighted harness, equal to 35% of the subject's body mass, will be worn around the waist and designed to replicate the pack weight carried by the soldiers during training and combat without obstructing the measurement of the scapular mechanics. Muscles to be assessed include the sternal portion of the pectoralis major, deltoids, trapezius, serratus anterior, supraspinatus, infraspinatus, subscapularis, and biceps brachii. Correct positioning of all electrodes will be confirmed through isolated manual muscle testing. The variables assessed include mean activation of each muscle's activity during the phase, as well as co-activation of the rotator cuff muscles. Co-activation of the supraspinatus-infraspinatus, supraspinatus-subscapularis, and subscapularis-infraspinatus will be calculated as described by Rudolph et al.

Collection of Strength Data

Bilateral isokinetic strength testing data will be collected using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY) to assess average peak torque to body weight and agonist/antagonist strength ratios for shoulder internal/external rotation, shoulder protraction/retraction, hip abduction/adduction, knee flexion/extension, and ankle dorsiflexion/plantarflexion. Torque values will automatically be adjusted for gravity by the Biodex Advantage Software v3.0 (Biodex Medical Inc., Shirley, NY). Subjects will be positioned and stabilized as per the manufacturer's guidelines to ensure proper alignment for testing and to restrict accessory movements. Three submaximal and three maximal effort practice trials will precede actual testing to ensure free movement, proper warm-up, and comfort of the subject throughout the range of motion. For knee strength testing, subjects will be asked to perform 10 knee flexion/extension concentric-concentric repetitions at 60°/second and 180□/second. For ankle strength testing, subjects will be asked to perform 10 ankle dorsiflexion/plantar flexion concentric-concentric repetitions at 60°/second and 180°/second. For shoulder strength testing, subjects will be asked to perform 10 shoulder internal rotation/external rotation concentric-concentric repetitions at 60°/second and 180°/second and 10 repetitions at 12.2 cm/second and 36.6 cm/second for shoulder protraction/retraction. Gravity-eliminated shoulder press and bench press will each be performed at 12.2 cm/second and 36.6 cm/second. For hip strength testing, subjects will perform five isometric abduction/adduction contractions at 15° of hip abduction.

Collection of Flexibility Data

Flexibility measurements of the shoulders (internal/external rotation, flexion, abduction), hips (internal/external rotation, abduction/adduction, flexion/extension), knees (hamstring flexibility, flexion/extension), and ankles (dorsiflexion/plantarflexion) will be assessed with a standard goniometer. The flexibility measurements are standard procedures used in the clinical practice by a physician to assess flexibility and have been described in Norkin and White. All measurements will be assessed as the joint is passively moved through its available range of motion. An investigator will passively move the joint while instructing the subject to not apply any resistance to the movement. Variables to be analyzed include the total degrees for each movement.

Collection of Posterior Shoulder Tightness (PST) Data

The PST will be assessed with the subject side-lying on a treatment table (Figure 3). Side-lying cross body humeral abduction test is the standard PST testing procedure described by Tyler et al. The subject will be asked to lay down on his/ her side for the side-lying cross body humeral adduction test. The subject's thorax will be aligned perpendicular to the treatment table with the spine in neutral flexion, extension, and rotation. With the tester facing the subject, excessive scapular movement will be restricted by stabilizing the lateral border of the scapula in the retracted position. Starting from humeral position of 90° abduction and neutral humeral rotation, the tester passively lowers the arm into horizontal adduction by griping the subjects' forearm just distal to the humeral epicondyles. The arm will be lowered until the full cross body humeral adduction range of motion is achieved or until the humerus starts to internally rotate. At the end range of motion, the second tester records the distance, in centimeters, between the medial epicondyle and the treatment table using a carpenter's square. This distance quantifies the subject's range of horizontal adduction, which reflects the degree of tightness in the posterior shoulder structures. The tests will be performed three times on each shoulder by the same testers for consistency. The distance between the table and the subject's medial epicondyle will be recorded, and the ratio between the PST on dominant v. non-dominant shoulders will be calculated.

Collection of Forward Shoulder Posture Data

Subjects will be asked to stand against the wall. Subjects will be asked to march 10 times in place and then roll their shoulder forward and backward three times and then nod their head backward and forward five times. This sequence of motions is performed to produce a natural standing posture. The subjects are then asked to move back towards to the wall until their buttocks touch the wall, and remain standing still in this posture during the test. The tester will measure the distance, in centimeters, between the wall and the anterior tip of the acromion process using a Double Square device (Figure 4). Measurements will be performed three times on each shoulder by the same investigator for all subjects. The average of the distances between the wall and the anterior tip of the acromion process will be recorded bilaterally, and the ratio between the forward shoulder postures of the dominant vs. non-dominant shoulders will be calculated.

Collection of Functional Balance Data

Functional balance testing will be assessed according to a balance scale that was developed in our laboratory. The purpose of this test is to assess postural control during a functional performance task. A numbered floor pattern will be measured for each individual subject according to body height. Individuals will begin at the starting point and hop to the next tape mark while maintaining their hands on their hips in single-leg stance. Individuals will progress through the course and will be scored for balance (touching down with the untested limb, limbs touching each other, excessive nontested limb movement, and hands off hips) and landing errors (not covering the tape mark, stumbling on landing, foot not facing forward with 10º of inversion or eversion, and hands off hip). Variables to be analyzed include balance and landing scores bilaterally.

Collection of Physiologic Data

Subjects will perform an incremental ramp protocol to determine maximal oxygen consumption, VO2 max, relative VO2 max (VO2 max/body weight), and lactate threshold. Subjects will be fitted with the K4b2 portable metabolic system and a heart rate monitor. A Modified

Maximal oxygen consumption data collection

Astrand protocol will be utilized for this study. The protocol consists of a five minute warm-up at a comfortable self-selected pace. An initial three minute workload at 0% grade will be self-selected by the subjects and based on a typical training pace. The adopted speed will permit the subject to perform 12 – 15 minutes of exercise before exhaustion. The incline will then be increased 2.5% every two minutes while the speed remains constant. Prior to each change in incline, a finger stick for a blood sample will be taken to assess blood lactate levels. The subjects will be instructed to continue running until exhaustion (defined as the inability to continue the test due to cardiovascular or peripheral inhibition). Heart rate and VO2 will be monitored continuously throughout the test. The test will be self-terminated by the subject and verified for 1) a plateau in VO2 is achieved with increasing intensity, 2) respiratory exchange ratio is > 1.1, and 3) heart rate is within 95% of age-predicted heart rate max (defined as 220 – age). The specific variables to be analyzed include absolute VO2 max, relative VO2 max (VO2 max/body weight), RER, and lactate threshold.

Body composition data collection

Collection of Body Composition Data

Subjects will be required to wear a tight fitting bathing suit or spandex outfit with a swim cap covering the hair to reduce air impedance. Calibration consists of placing an object of known volume into structure in order to assure maximum accuracy. Total calibration time is approximately 2-3 minutes. Subjects will enter the BOD POD and sit within the system for approximately one minute. Subjects will breathe regularly and remain motionless during the testing procedure. The specific variables to be analyzed include percent body fat and lean tissue.

Collection of Anaerobic Power Data

The test is performed using an electronically braked bicycle ergometer. After a 10 minute warm up the athlete begins pedaling as fast as possible without any resistance. Within 3 seconds, a fixed resistance is applied to the flywheel and the athlete continues to pedal "all out" for 30 seconds. Flywheel resistance equals 0.075 kg per kg body mass. Resistance often increases to 1.0 kg x body mass or higher (up to 1.3 kg) when testing power and sprint athletes. An electrical counter continuously records flywheel revolutions in 5-second intervals. The highest power output, observed during the first 5 sec of exercise, indicates the energy generating capacity of the immediate energy system (intramuscular high energy phosphates adenosine triphosphate (ATP) and phosphocreatine (PC).

Data Analysis Summary

For purposes of evaluating the tactical athlete's physical and physiological ability, the human performance data were benchmarked against a group of elite athletes, elite triathletes, or elite tactical athletes (top 10th percentile of 101st Soldiers). By definition, "consistent" within this report for comparison of data will refer to data within 10% of a normative value. A secondary analysis identified subsets of Soldiers with data below normative threshold values for injury or performance.
The data indicated several areas where the Soldiers could improve their physical readiness, and mechanical and nutritional preparation for tactical operations. Initial analysis of the sample size compared to an athletic population revealed the following:

NUTRITION: As indicated by the nutrition history questionnaire and 24 hour dietary recall, Soldiers are not meeting recommended nutritional needs for performing moderate to heavy physical training. Prolonged inadequate consumption of calories and protein will result in weight loss, loss of muscle mass, decreased strength/power output, and reduced endurance capacity.

As carbohydrates provide the primary fuel source for working muscle during both aerobic and anaerobic activities, refueling of depleted muscle glycogen reserves is detrimental to a Soldier's ability to train and maintain high levels of activity. Moderately active Soldiers participating in 1.5 hours of PT/day should consume 7 g carbohydrate/kg body weight/day.

To adequately meet protein needs, Soldiers should consume between 1.2-1.7 g protein/kg body weight per day. Strength trained individuals and those wishing to increase muscle power and size, should consume 1.6 g protein/kg body weight per day.

Excess consumption of foods high in fat, often replaces those rich in carbohydrate and protein, causing a nutritional imbalance. As previously mentioned, this imbalance of nutrients may result in impaired physical performance. Soldiers should decrease fat intake to fall within the range of 0.8-1.0 g (moderate PT) to 2.0 g (heavy PT) fat per kg body weight/day.

Additionally important for recovery and performance, is the consumption of adequate amounts of fluid and fuel before, during, and after training sessions. Prior to PT, a light snack that is high in carbohydrate, low to moderate in protein, and low in fat will be beneficial to performance, especially if the training session occurs in the morning following an 8-12 hour overnight fast. Of equal importance is a post workout recovery meal or snack, containing both carbohydrate and a small amount of protein within the first 30 minutes following physical training. Soldiers should aim to be euhydrated prior to PT, hydrate with fluids during PT, and replace fluids lost after exercise sessions.

STRENGTH: Group average strength deficits were demonstrated in greater than 30% of the Soldiers in almost all strength variables. More specifically, below minimum threshold scores were displayed by up to 38% of the Soldiers for shoulder strength, 49% for knee strength, and 32% for torso strength. In addition, greater than 53% of the Soldiers demonstrated agonist/antagonist muscle imbalance. More specifically, muscular imbalances were identified in up to 67% of the Soldiers for shoulder external/internal rotation strength, 96% for knee flexion/extension strength, and 54% for ankle inversion/eversion strength. Further, greater than 34% of Soldiers demonstrated bilateral strength asymmetries, with bilateral asymmetries identified in up to 59% of Soldiers for the shoulder, up to 54% for the knee and ankle, and up to 37% for the trunk. Lack of strength can significantly impair joint stability. In addition, inefficient agonist/antagonist strength and bilateral strength asymmetries of greater than 10% have been demonstrated to increase the risk of musculoskeletal injury.

FLEXIBILITY: Group average flexibility was within normal limits, however significant deficits were noted in the hamstrings and calf musculature with 65% and 37% below threshold, respectively.

BALANCE: Single leg balance is important to measure because poor performance of this task may indicate greater risk for ankle and knee injury. The overall average of both male and female Soldiers was within normal limits when compared to the triathlete model for both eyes opened and eyes closed single leg balance. The average performance of eyes open single limb balance of the male group was up to 61% worse than the top 10th percentile of male Soldiers, and the average performance of female Soldiers was up to 70% worse than the top 10th percentile of their group. For eyes closed balance the male average was up to 106% worse than their top 10th percentile, and the female average was up to 93% worse than their top 10th percentile.

PHYSIOLOGICAL: Group average body fat was high with 85% above threshold, and a range of 0-50%* above threshold when separated by age. Anaerobic power and anaerobic capacity were 94% (athlete) and 99% (athlete) below threshold, respectively. VO2 max and lactate threshold were 70% and 68% below threshold, respectively.

BIOMECHANICS: Lower extremity biomechanics during landings were studied as this activity is associated with a high number of musculoskeletal injuries. Upon landing, 26% of the Soldiers demonstrated decreased hip flexion which reduces the efficiency of the strong hip musculature to absorb joint forces. Knee flexion during landing was within normal limits, however 50% landed with a valgus knee position and high vertical ground reaction forces, both of which may ultimately lead to ligamentous sprain and potential rupture.

Nutrition

Carbohydrate Requirements for Physical Training

Testing methodology: Nutrition History and 24 hour Diet Recall

Purpose: Carbohydrates should be provided based on training time and body weight in order to individualize specific muscle fuel needs for the Soldiers. The aim is to achieve carbohydrate intakes to meet the fuel requirements of the training program and to optimize restoration of muscle glycogen stores between workouts so that Soldiers are able to perform maximally and are combat ready more quickly.

Background: Carbohydrate is the major fuel source for skeletal muscle and the brain. In the muscle, stored carbohydrate (glycogen) can be used for both anaerobic (short-term, high-intensity) and aerobic (endurance) activity. During prolonged strenuous physical activity, muscle glycogen and blood glucose are the major substrates for oxidative metabolism. A retrospective review of 11 different field studies involving 781 Soldiers found an average CHO intake of 290 + 70 grams per day, well below the NATO panel recommendation of >450 grams per day needed for glycogen synthesis. Research has shown that CHO intake will also improve performance on military tasks.
Carbohydrate requirements will be estimated based on daily hours of physical training using the following:

Grams Carbohydrate/kg body weight/day	Training hours/day
6-7 g/kg/day	1 hour/day
8 g/kg/day	2 hours/day
10 g/kg/day	3 hours/day
12-19 g/kg/day	>4 hours/day

Data and Results:

- 93% of Soldiers did not consume the recommended amount of carbohydrate (7 g/kg body weight for 1 ½ hours PT/day
- 87% of Soldiers did not consume the NATO recommendation of >450 g/day

Summary:
Currently, only 7% of Soldiers are eating the recommended amount of carbohydrate on a daily basis to replace used glycogen stores from physical training. Furthermore, 77% of Soldiers are not eating the recommended amount of carbohydrates for the “average low active adult male” (5 g carbohydrate/kg body weight). When carbohydrate reserves are depleted during/after physical training and are not sufficiently replaced with adequate amounts of daily carbohydrate, there is a switch to a fat-predominant fuel metabolism which is characterized by muscle and central fatigue and the inability to maintain power output. Ultimately this results in a decrease in physical performance. In order for Soldiers to train at a higher level, it is vital they consume sufficient carbohydrates on a daily basis.

Protein Requirements for Increasing Muscular Strength and Endurance

Testing Methodology: Nutrition History and 24 hour Diet Recall

Purpose: Examine protein intake as it relates to increasing muscular strength and power

Background: The 0.8 grams of protein per kilogram body weight guidelines (Recommended Daily Allowance/RDA) represent a liberal requirement believed to be adequate for all people. A protein intake of between 1.2-1.7 grams per kg of body mass should adequately meet the possibility for added protein needs during strenuous physical training. The protein requirement for strength trained individuals is on the higher side of the range (1.6-1.7g/kg body weight) allowing for additional protein necessary to increase muscle mass, strength and or power. Equally or more important to increase muscle strength and size is the provision for additional calories above the amount necessary for maintenance.

Data and Results:
Protein Requirements: (1.6 g/kg body weight) for increasing muscle strength

- 31% met (or exceeded) the recommended protein requirement
- 69% did not meet recommended protein requirement
- 85% met the RDA (0.8 g protein/kg body weight) for the “average adult male”

Summary:
Currently ~31% of the tested Soldiers are meeting their estimated protein requirements for moderate to heavy physical training. Of these, 54% of soldiers also met or exceeded their estimated energy requirements, which provides the right environment for increasing muscle strength and size. Forty-six percent of Soldiers who met or exceeded their protein requirements did not meet their estimated energy requirements and therefore may be metabolizing the excess protein to meet their energy needs. Sixty-nine percent of Soldiers did not consume adequate protein and of these, 87% also did not consume adequate calories. Consuming suboptimal calories and protein will result in decreased body mass, muscle strength, size and power output.

Distribution of Fat in the Diet

Testing methodology: Nutrition History and 24 hour Diet Recall

Purpose: In order to maximize physical performance, it is essential to provide adequate calories, carbohydrate and protein in the diet. Once carbohydrate and protein needs are met, the balance of calories can be supplied by fat in the range of 0.8-1.0 g (moderate PT) to 2.0 g (heavy PT longer duration >4 hours/day) fat per kg body weight.

Background: Fat along with carbohydrate is oxidized in the muscle to supply energy to the exercising muscles. The extent to which these sources contribute to energy expenditure depends on a variety of factors, including exercise duration and intensity, nutritional status, and fitness level. In general as exercise duration increases, exercise intensity decreases and more fat is oxidized as an energy substrate. During high intensity physical training, predominantly carbohydrate is oxidized to fuel the muscles. To improve physical performance, individuals need to consume enough calories, carbohydrates, and protein to support the demands of training in order to train at a higher level. In planning a diet to provide the nutrients to support the training program, carbohydrate and protein needs are determined first and then the remaining calories are designated to fat which typically ranges from 0.8-2.0 g fat per kg body weight based on caloric needs, body composition goals and duration and intensity of training.

From a health prospective, the Dietary Reference Intakes (DRIs) have defined an Acceptable Macronutrient Distribution Range (AMDR) for fat as 20-35% of daily energy needs for all adults. The AMDR is defined as a range in intakes for a particular energy source that is associated with reduced risk of chronic diseases while providing adequate intake of essential nutrients.

Data and Results:

- 63% of Soldiers consumed greater than 0.8 g to < 2.0 g fat per kg body weight (recommended range)
- 31% of Soldiers consumed less than 0.8 g fat per kg body weight, and of these 100% consumed insufficient energy (kcals) to meet energy needs
- 7% of Soldiers consumed greater than 2.0 g fat per kg body weight
- 62% of Soldiers consumed greater than 30% of calories from fat
- 14% of Soldiers exceeded their estimated energy requirements. These individuals also had the highest consumption of fat (0.8-5.79 g/kg body weight).
- 26% of Soldiers met their energy requirements, of these however, 28% did not meet either their protein or carbohydrate requirements, yet exceeded 1.0 g fat per kg body weight.
- 74% of Soldiers did not meet their energy requirements and of these,
    - 30% failed to meet both carbohydrate and protein requirement, yet consumed >1.0 g fat per kg body weight
    - 35% failed to meet the recommended amounts for all the macronutrients (carbohydrate, protein and fat)
    - 63% failed to meet carbohydrate requirements but either met or exceeded protein and fat recommendations

Summary:
To train at an optimal level, it is important to consume sufficient calories, carbohydrates, protein and some fat. However, if foods high in fat replace carbohydrate and protein foods in the diet, such that these two macronutrients fall below recommended amounts, it may impair physical performance. It is recommended that these Soldiers decrease the amount of fat in the diet and increase carbohydrate and protein foods (lower in fat).

From a health prospective, 62% of Soldiers are currently consuming a diet that is >30% of calories from fat. High fat diets increase the risk for overweight, high body fat, high blood pressure, diabetes mellitus, and cardiovascular disease. Decreasing the overall fat content of the diet and replacing the calories with high carbohydrate, moderate protein foods (that are low in fat), would decrease health risk and improve physical training.

Timing and Type of Post Physical Training Protein Intake

Testing Methodology: Nutrition History and 24 hour Diet Recall

Purpose: Examine protein intake and timing of intake after physical training

Background: Immediately after (within 30 minutes) physical training, it is recommended to consume a snack/meal that contains both carbohydrate and a small amount of protein. Nutrient consumption with resistance training stimulates muscle protein synthesis and inhibits the exercise induced muscle protein breakdown, thereby muscle mass is gradually increased. Consuming a post exercise snack or meal containing carbohydrate and protein will provide the essential nutrients for faster muscle recovery. Expedited muscle recovery allows an individual to sustain a higher physical work capacity (strength and endurance) in subsequent periods of exertion, thus increasing combat readiness.

Data and Results:
Timing and Content of Pre-Training Meal/Snack

- 63% of Soldiers do not consume a meal/snack prior to PT
- Of the 37% of Soldiers that do consume a meal/snack prior to PT
  - Timing
    - 100% consume a meal/snack within 1 hour prior to PT
  - Type of Meal/Snack Consumed
    - 72% consume a meal/snack that contains both carbohydrate and protein
    - 25% consume a meal/snack that contains only carbohydrate

Timing and Content of Post- Training Snack

- 67% of Soldiers consume a snack/meal post PT
  - Timing
    - 67% consume a meal/snack within 1 hour post PT
    - 28% consume a meal/snack between 1 to 2 hours post PT
    - 5% consume a meal/snack between 2 to <4 hours post PT
  - Type of Meal/Snack Consumed
    - 86% consume a meal/snack that contains both carbohydrate and protein
    - 0% consume a meal/snack that contains only protein
    - 14% consume a meal/snack hat contains only carbohydrate

Summary:
Pre-Training Meal/Snack Consumption
Thirty-Seven percent of Soldiers indicated that they consume a meal/snack prior to PT. The most common food items eaten were yogurt, cereal, protein shakes, granola bars, and fruit. Eating a light snack high in carbohydrate, low to moderate protein and low fat prior to PT is beneficial especially if it occurs in the morning after an 8-12 hour overnight fast. This will supply the body with carbohydrate that will increase blood glucose and allow the body to use less stored carbohydrate, thus allowing an individual to exercise at a higher intensity for a longer duration.

Post- Training Meal/Snack Consumption
All Soldiers tested reported eating a meal/snack within 4 hours of the completion of PT. Ninety-five percent consume their meal/snack within 2 hours post PT. To expedite muscle glycogen repletion, it is recommended that individuals consume a meal/snack that contains carbohydrate and protein as soon after exercise as possible (within 30 minutes). Consuming adequate carbohydrate as part of a meal within 2 hours post exercise will allow for adequate muscle glycogen repletion but it will take a longer period of time (approximately 24 hours).

Additionally, 86% Soldiers consumed a snack/meal that contained both carbohydrate and protein, such as cereal, milk, fruit, eggs, sausage, toast and yogurt. Ideally, consuming food that contains a moderate amount of carbohydrate and a small amount of protein within 30 minutes will expedite muscle glycogen resynthesis (as previously mentioned) and help to reduce muscle protein breakdown. This is especially important for Soldiers participating in subsequent training bouts separated by shorter rest periods (<8 hours).

Adequate Fluids during Exercise to Stay Hydrated and Maintain Energy

Testing Methodology: Nutrition History

Purpose: Examine fluid habits before, during and after exercise

Background: The US Army's fluid replacement guidelines were revised in 1999 and emphasize the avoidance of dehydration to prevent performance degradation and reduce the risk of heat injury. During the 10-yr period between 1989 and 1999, there were 190 hospitalized cases of water intoxication (hyposmolality/hyponatremia) in the US Army, suggesting the fluid replacement guidelines needs to be adjusted to prevent hyperhydration. The goal is to provide adequate fluids to avoid dehydration but not in excess to avoid water intoxication. Soldiers should be well hydrated when beginning to exercise and accustomed to consuming fluid at regular intervals (with or without thirst) during training sessions to minimize fluid losses that may result in a decrease in physical performance. If time permits, consumption of normal meals and beverages will restore euhydration. Individuals needing rapid and complete recovery from excessive dehydration can drink ~1.5 L of fluid per kg of body weight lost (23 oz per pound). Consuming beverages and snacks with sodium will help expedite rapid and complete recovery by stimulating thirst and fluid retention.

Data and Results:
Fluids before Physical Training

- 22% of Soldiers do not drink fluids prior to PT
- Of the 78% of Soldiers that do drink fluids prior to PT
  - 75% consume a water
  - 89% consume a water and/or sports drinks
  - 13% consume sports drink
  - 11% consumed coffee, Red Bull, sweetened carbonated beverages, or juice.

Fluids during Physical Training

- 37% of Soldiers do not drink fluids during PT
- Of the 63% of Soldiers that did drink fluids during PT
  - 90% consume a water
  - 99% consume a water and/or sports drinks
  - 9% consume sports drink only
  - 1% consumed (Crystal Light, carbohydrate and amino acid mixed sports drinks)

Fluids after Physical Training

- 87% of Soldiers consumed fluids post PT
  - 60% of Soldiers consumed water
  - 89% of Soldiers consumed water and/or sports drinks
  - 29% of Soldiers consumed sports drink
  - 11% of Soldiers consumed other (juice, chocolate milk, Crystal Light, coffee)

Summary:
The majority of Soldiers (78%) consume some fluid before physical training in the morning. The beverage of choice is water (>75%), followed by sports drinks. **Since many of the Soldiers do not consume food prior to morning physical training and their last meal would have been the night before, it would be beneficial to drink a beverage that contains a source of carbohydrate for energy.**

Ninety percent of the tested Soldiers consume water during physical training and 99% drink either water and/or sports drinks, sports drinks or Crystal Light. The US Army's fluid replacement guidelines provide recommendations based on length of training, intensity and temperature. Ideally, beverages consumed during training lasting longer than 60 minutes should contain 6-8% carbohydrate, 10-20 mEq sodium and chloride (constitution of most Sports drinks). Sodium and carbohydrate help speed replenishment of fluid and energy reserves as well as replace sodium lost due to sweating.

Eight-seven percent of Soldiers consumed fluids after physical training. The majority drank water, followed by sports drinks sports drinks (CHO and electrolytes), chocolate milk and Crystal Light. **Ideally, the beverage should contain carbohydrate, electrolytes and a small amount of protein.** For example, low fat chocolate milk, or sports drinks that contain protein are good choices. Water along with a snack or meal with carbohydrate, protein and electrolytes is also sufficient. Consuming a post exercise beverage or snack/meal containing carbohydrate and protein will provide the essential nutrients for faster muscle recovery.

	Pre-Training	**Training**	**Post-Training**
Low Intensity (<55% Max HR)	Water	Water	Water or sports drink
Moderate Intensity (>55-<70% Max HR) - Short Duration (< 60 minutes)	Water	Water	Sports Drink
Moderate Intensity(>55-<70% Max HR)- Long Duration (> 60 minutes)	Water or Sports Drink*	Sports Drink	Sports Drink
High Intensity (>70% Max HR)- Short Duration (< 60 minutes)	Water or Sports Drink*	Sports Drink	Sports Drink
High Intensity (>70% Max HR)- Long Duration (> 60 minutes)	Water or Sports Drink*	Sports Drink	Sports Drink

This is also largely dependent on acclimatization of the individual and environmental temperature.

*If an individual has consumed a snack/meal within 1-2 hours prior to training, water is sufficient to drink, otherwise a sports drink that has carbohydrate and electrolytes is advisable.

Energy Requirements for Physical Training

Testing methodology: Nutrition History and 24 hour Diet Recall

Purpose: To determine the amount of calories consumed on a daily basis and compare it to the calories required to fuel daily physical training.

Background:
Energy expenditure data of military personnel reported in the literature has ranged from 3100 to over 8000 kcals per day. The large range reflects differences not only in the volume, intensity, operational and environmental demands of the physical activity being performed, but in the variety methods used to obtain the data. It has been reported that the US Army Rangers had an average daily total energy expenditure of 4,500 kcal per day during garrison training and 5,200 kcal per day during field training.

Estimating Energy Requirements:

Moderate physical training	**19 kcals/pound males**
	17 kcals/pound females

Data and Results:
Moderate Physical Training

- 13% Soldiers met the estimated energy requirements (>90 to < 110%) for an adult male participating in moderate physical training
- 74% Soldiers did not meet the estimated energy requirements (<90%) for an adult male/female participating in moderate physical training
- 13% Soldiers exceeded the estimated energy requirements (>110%) for an adult male/female participating in moderate physical training

Summary:

Moderate Physical Training
In order to maximize work performance during high volume training, energy intake should at least match energy expenditure. Currently ~13% of the tested Soldiers are meeting the estimated energy requirements to meet daily energy requirements for moderate physical training. Additionally 13% consumed greater than 110% of their energy requirements for moderate physical training. Consuming excess calories above estimated needs may be desirable if the soldier wants to gain lean body mass. However, it may also result in increased body weight and higher body fat. Approximately 74% of Soldiers reported consuming less than 90% of estimated energy needs for moderate physical training. If this practice occurs regularly, it will result in weight loss, loss of muscle mass, decrease in muscle strength and endurance and a decline in physical performance.

**Important to note, that these are only estimates of energy expenditure based on a formula and not measured energy needs. One of the goals of this research project is to measure the energy expenditure of Soldiers during field training using the portable respiratory metabolic system to more accurately predict energy requirements. It is also dependent on accurate energy intake data from the nutrition history forms and 24 hour recall information provided by the Soldiers.

Strength

Shoulder Internal Rotation (IR) and External Rotation (ER) Strength

Testing methodology:
Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)
5 repetitions
Average peak torque/BW

Purpose: Examine rotator cuff strength

Background: Proper rotator cuff strength (internal and external rotation) is critical for the performance of demanding overhead tasks and maneuvers involving the upper extremity. In addition, the stability of the glenohumeral joint is significantly dependent upon the health of the rotator cuff as a source of dynamic stabilization for the joint. Deficiencies in strength of the rotator cuff will predispose the shoulder to altered joint kinematics leading to potential trauma including acute and/or chronic instability and impingement syndromes.

Data and Results:

Male

RIGHT

	IR (% BW)	ER (% BW)	ER/IR (Ratio)
Top 10th %tile 101st	78.9	52.9	--
Top 25th %tile 101st	69.1	46.4	--
50th %tile 101st	58.9	40.7	--
Bottom 25th %tile 101st	48.6	35.6	--
Triathletes	64.3 ± 9.7	46.5 ± 6.9	0.73 ± 0.09
Athlete*	53.0	40.0	0.77
101st	59.6 ± 15.1	41.4 ± 8.6	0.71 ± 0.14

LEFT

	IR (% BW)	ER (% BW)	ER/IR (Ratio)
Top 10th %tile 101st	74.2	47.3	--
Top 25th %tile 101st	62.1	41.9	--
50th %tile 101st	52.5	36.6	--
Bottom 25th %tile 101st	43.8	31.9	--
Triathletes	65.5 ± 13.6	44.5 ± 7.3	0.69 ± 0.12
Athlete*	53.0	40.0	0.77
101st	54.6 ± 15.4	37.3 ± 7.7	0.71 ± 0.15

*** Oyama 2006**

Female

RIGHT

	IR (% BW)			ER (% BW)			ER/IR (Ratio)		
Top 10th %tile 101st	46.6			36.7			--		
Top 25th %tile 101st	40.7			33.3			--		
50th %tile 101st	34.5			29.3			--		
Bottom 25th %tile 101st	29.4			24.7			--		
Triathletes	40.8	±	8.8	34.9	±	6.7	0.87	±	0.16
Athlete*	53.0			40.0			0.77		
101st	35.2	±	9.1	29.2	±	5.3	0.87	±	0.23

LEFT

	IR (% BW)			ER (% BW)			ER/IR (Ratio)		
Top 10th %tile 101st	45.4			33.3			--		
Top 25th %tile 101st	39.0			29.1			--		
50th %tile 101st	32.1			24.8			--		
Bottom 25th %tile 101st	27.1			23.0			--		
Triathletes	43.0	±	8.2	32.7	±	7.4	0.76	±	0.11
Athlete*	53.0			40.0			0.77		
101st	32.8	±	8.5	25.9	±	5.1	0.82	±	0.18

*** Oyama 2006**

Summary: Overall, male Soldiers demonstrated internal rotation strength up to 13% greater than the athlete model and 26% less than top 10th percentile of 101st Soldiers. External rotation strength was consistent with the athlete model and up to 22% less than the top 10th of male Soldiers. External/internal rotation strength ratio was inefficient in up to 64% of the male Soldiers. Asymmetrical strength differences were identified in up to 59% of the male Soldiers.

Overall, female Soldiers demonstrated internal rotation strength up to 38% less than the athlete model and up to 28% less than top 10th percentile of 101st Soldiers. External rotation strength was up to 35% less than the athlete model and up to 21% less than the top 10th of female Soldiers. External/internal rotation strength ratio was inefficient in up to 67% of the female Soldiers. Asymmetrical strength differences were identified in up to 58% of the female Soldiers.

Knee Flexion and Extension Strength

Testing methodology:
Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)
5 repetitions
Isokinetic: 60°/sec
Average peak torque/BW

Purpose: Examine knee flexion and extension strength

Background: Adequate strength of the hamstring and quadriceps muscle groups is vital for the performance of dangerous landing tasks and maneuvers associated with tactical operations training. These muscle groups contribute to the dissipation of forces imposed on and neuromuscular control of the knee joint during demanding lower extremity activities. Further, the maintenance of appropriate strength ratios between the hamstring and quadriceps muscle groups may minimize the risk factors associated with traumatic and overuse leg injuries during training.

Data and Results:

Male

RIGHT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 101st	147.8	294.3	--
Top 25th %tile 101st	130.9	263.7	--
50th %tile 101st	115.4	233.6	--
Bottom 25th %tile 101st	98.2	202.1	--
Triathletes	128.0 ± 22.6	242.1 ± 50.4	0.55 ± 0.09
Athlete*	170.0	270.0	0.65
101st	114.9 ± 26.2	235.1 ± 47.0	0.50 ± 0.13

LEFT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 101st	143.0	276.3	--
Top 25th %tile 101st	129.5	251.3	--
50th %tile 101st	111.1	225.9	--
Bottom 25th %tile 101st	94.6	200.2	--
Triathletes	128.5 ± 23.2	241.3 ± 42.9	0.53 ± 0.06
Athlete*	170.0	270.0	0.65
101st	111.7 ± 25.7	224.8 ± 43.8	0.50 ± 0.12

*** Newman 2004**

Female

RIGHT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 101st	119.4	238.5	--
Top 25th %tile 101st	104.0	206.3	--
50th %tile 101st	93.7	185.5	--
Bottom 25th %tile 101st	76.4	167.1	--
Triathletes	115.4 ± 15.4	216.5 ± 21.7	0.52 ± 0.04
Athlete*	170.0	270.0	0.65
101st	91.3 ± 22.2	187.1 ± 38.6	0.49 ± 0.06

LEFT

	Flexion (% BW)	Extension (% BW)	Flex/Ext (Ratio)
Top 10th %tile 101st	114.9	233.4	--
Top 25th %tile 101st	103.7	191.4	--
50th %tile 101st	87.1	169.0	--
Bottom 25th %tile 101st	74.2	148.3	--
Triathletes	114.0 ± 14.9	211.4 ± 34.7	0.54 ± 0.05
Athlete*	170.0	270.0	0.65
101st	87.2 ± 21.2	172.9 ± 39.5	0.51 ± 0.10

*** Newman 2004**

Summary: Overall, the male Soldiers were up to 34% below the athlete model for knee flexion strength and up to 22% below the top 10th percentile of Soldiers. Knee extension strength was up to 17% below the athlete model and up to 20% below the top 10th percentile of male Soldiers. Knee flexion/extension ratio was inefficient in up to 91% of the male Soldiers. Asymmetrical strength differences were identified in up to 54% of the male Soldiers.

Overall, the female Soldiers were up to 49% below the athlete model for knee flexion strength and up to 24% below the top 10th percentile of Soldiers. Knee extension strength was up to 36% below the athlete model and up to 26% below the top 10th percentile of female Soldiers. Knee flexion/extension ratio was inefficient in up to 96% of the female Soldiers. Asymmetrical strength differences were identified in 52% of the female Soldiers.

Ankle Inversion and Eversion Strength

Testing methodology:
Lafayette handheld dynamometer
Inversion/eversion with hip and knee in 90º of flexion
Average of 3 measurements (Nm)

Purpose: Examine ankle inversion and eversion strength

Background: Ankle invertors and evertors serve a critical role in providing dynamic stabilization and neuromuscular control to the ankle joint during closed kinetic chain activities such as those experienced during the demanding tasks encountered by Special Operations Soldiers during tactical training. Incorporating strengthening exercises for these important muscle groups will dramatically impact the deficits that are seen in this variable and likely significantly decrease the risk factors associated with recurrent ankle injuries reported.

Data and Results:

Male

RIGHT

	Inversion (% BW)			Eversion (% BW)			Inv/Ev (Ratio)		
Top 10th %tile 101st	44.1			40.0			--		
Top 25th %tile 101st	40.1			34.5			--		
50th %tile 101st	34.6			29.4			--		
Bottom 25th %tile 101st	29.3			25.3			--		
Triathletes	23.6	±	3.7	21.5	±	2.3	1.1	±	0.13
Normative	22.0	±	4.4	23.3	±	6.6	1.12		
101st	34.6	±	7.4	30.1	±	6.6	1.16	±	0.21

LEFT

	Inversion (% BW)			Eversion (% BW)			Inv/Ev (Ratio)		
Top 10th %tile 101st	41.9			39.7			--		
Top 25th %tile 101st	38.5			35.5			--		
50th %tile 101st	32.8			30.3			--		
Bottom 25th %tile 101st	28.1			26.1			--		
Triathletes	23.2	±	4.8	21.6	±	3.5	1.1	±	0.18
Normative	22.0	±	4.4	23.3	±	6.6	1.12		
101st	33.1	±	6.9	30.8	±	6.6	1.09	±	0.19

***Kellen 2008**

Female

RIGHT

	Inversion (% BW)			Eversion (% BW)			Inv/Ev (Ratio)		
Top 10th %tile 101st	34.1			30.2			--		
Top 25th %tile 101st	30.6			24.7			--		
50th %tile 101st	23.6			21.3			--		
Bottom 25th %tile 101st	19.6			18.3			--		
Triathletes	19.2	±	2.2	17.0	±	1.6	1.14	±	0.12
101st	24.9	±	6.6	21.7	±	6.0	1.18	±	0.26

LEFT

	Inversion (% BW)			Eversion (% BW)			Inv/Ev (Ratio)		
Top 10th %tile 101st	33.0			31.5			--		
Top 25th %tile 101st	29.0			26.4			--		
50th %tile 101st	22.8			21.1			--		
Bottom 25th %tile 101st	18.7			17.6			--		
Triathletes	19.0	±	3.2	18.2	±	4.2	1.08	±	0.22
101st	23.4	±	6.2	22.0	±	6.2	1.09	±	0.19

Summary: Inversion strength was up to 22% less and eversion strength was up to 25% less than the top 10th percentile of male Soldiers. Inversion/eversion strength ratio was inefficient in 53% of the male Soldiers. Asymmetrical differences were identified in up to 54% of the male Soldiers.

Inversion strength was up to 29% less and eversion strength was up to 30% less than the top 10th percentile of female Soldiers. Inversion/eversion strength ratio was inefficient in up to 61% of the female Soldiers. Asymmetrical differences were identified in 51% of the female Soldiers.

Torso Right and Left Rotation Strength

Testing methodology:
Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)
5 repetitions
Average peak torque/BW

Purpose: Examine right and left torso rotation strength

Background: Adequate core strength is the pillar of maximal physical performance and contributes significantly to upper and lower extremity mobility, and strength. Improving torso strength will have a positive impact on virtually every other performance variable and decrease the risk of injury as a result of enhanced musculoskeletal and cardiorespiratory efficiency.

Data and Results:

Male

	Right Rotation (% BW)	Left Rotation (% BW)	Right/Left (Ratio)
Top 10th %tile 101st	191.4	190.6	--
Top 25th %tile 101st	170.6	169.4	--
50th %tile 101st	148.5	147.2	--
Bottom 25th %tile 101st	126.1	124.7	--
Triathletes	151.5 ± 25.9	154.6 ± 30.9	1.00 ± 0.09
Athlete*	157.3	157.3	--
101st	147.6 ± 32.7	147.7 ± 33.0	1.01 ± 0.13

Female

	Right Rotation (% BW)	Left Rotation (% BW)	Right/Left (Ratio)
Top 10th %tile 101st	139.2	146.2	--
Top 25th %tile 101st	124.3	126.2	--
50th %tile 101st	103.6	105.8	--
Bottom 25th %tile 101st	93.6	92.2	--
Triathletes	118.5 ± 24.6	114.9 ± 25.7	0.98 ± 0.11
Athlete*	157.3	157.3	--
101st	106.7 ± 24.8	108.7 ± 25.1	1.02 ± 0.09

*** Sell 2007**

Summary: On average, male Soldiers were within normal limits for torso rotation strength and female Soldiers were up to 32% less than the athlete model for torso rotation strength. Male Soldiers were up to 23% less than the top 10th percentile of male Soldiers and females were up to 26% less than the top 10th percentile female Soldiers. Right/left torso rotation was inefficient in 37% of the male Soldiers and 34% of the female Soldiers.

Musculoskeletal Flexibility

Shoulder Flexion, Extension, and Abduction Flexibility

Testing methodology:
Digital inclinometer
Average of 3 measurements (°)

Purpose: Examine shoulder flexion, extension, and abduction flexibility

Background: Shoulder flexion, extension and abduction range of motion is critical for maintenance of proper glenohumeral and shoulder girdle kinematics. A deficit in shoulder ROM will significantly impact overall performance during demanding overhead and upper extremity tasks and predispose the Soldier to potentially traumatic and/or chronic pathologies.

Data and Results:

Male

RIGHT

	Flexion (degrees)	Extension (degrees)	Abduction (degrees)
Top 10th %tile 101st	197	86	218
Top 25th %tile 101st	192	78	213
50th %tile 101st	187	70	206
Bottom 25th %tile 101st	182	59	201
Triathletes	177 ± 11	69 ± 9	194 ± 11
Athlete*	168	81	172
Clinical Range	170-190	50-70	170-190
101st	187 ± 7	68 ± 14	206 ± 9

LEFT

	Flexion (degrees)	Extension (degrees)	Abduction (degrees)
Top 10th %tile 101st	198	87	219
Top 25th %tile 101st	192	80	213
50th %tile 101st	188	73	206
Bottom 25th %tile 101st	183	63	199
Triathletes	177 ± 11	71 ± 9	193 ± 10
Athlete*	168	81	172
Clinical Range	170-190	50-70	170-190
101st	188 ± 7	71 ± 13	205 ± 10

*** Brown 1988**

Female

RIGHT

	Flexion (degrees)			Extension (degrees)			Abduction (degrees)		
Top 10th %tile 101st	202			94			222		
Top 25th %tile 101st	193			90			217		
50th %tile 101st	190			82			211		
Bottom 25th %tile 101st	186			72			207		
Triathletes	188	±	11	80	±	8	198	±	18
Athlete*	168			81			172		
Clinical Range	170-190			50-70			170-190		
101st	188	±	15	80	±	12	212	±	9

LEFT

	Flexion (degrees)			Extension (degrees)			Abduction (degrees)		
Top 10th %tile 101st	196			95			220		
Top 25th %tile 101st	193			91			215		
50th %tile 101st	190			85			210		
Bottom 25th %tile 101st	186			77			205		
Triathletes	189	±	12	82	±	6	201	±	11
Athlete*	168			81			172		
Clinical Range	170-190			50-70			170-190		
101st	187	±	17	83	±	12	210	±	7

*** Brown 1988**

Summary: On average, the male Soldiers demonstrated shoulder flexion range of motion consistent with the top 10th percentile of male Soldiers, and male triathletes bilaterally, and up to 12% more shoulder flexion compared to athletes. The average shoulder extension range of motion was consistent with the triathletes, and up to 16% and 20% less compared to the athletes and top 10th percentile of male Soldiers respectively. On average, the male Soldiers demonstrated shoulder abduction range of motion consistent with the top 10th percentile of male Soldiers, and male triathletes bilaterally, and up to 20% more shoulder flexion compared to athletes. Suboptimal shoulder extension range of motion was demonstrated in up to 59% of the top 10th percentile of male Soldiers.

On average, the female Soldiers demonstrated shoulder flexion range of motion consistent with the top 10th percentile of female Soldiers, and female triathletes bilaterally, and up to 12% more shoulder flexion compared to athletes. The average shoulder extension range of motion was consistent with the top 10th percentile of female soldiers, triathletes, and athletes bilaterally. On average, the female Soldiers demonstrated shoulder abduction range of motion consistent with the top 10th percentile of female Soldiers, and female triathletes bilaterally, and up to 23% more shoulder flexion compared to athletes. Suboptimal shoulder extension range of motion was demonstrated in up to 28% of the top 10th percentile of female Soldiers.

Shoulder External and Internal Rotation and Posterior Shoulder Tightness Flexibility

Testing methodology:
Digital inclinometer
Average of 3 measurements (°)

Purpose: Examine shoulder external and internal rotation and PST flexibility

Background: A balance between internal and external rotation flexibility is desired to maintain appropriate glenohumeral joint kinematics and contributes to better physical performance during overhead activities. Posterior shoulder tightness may be the result of inflexible rotator cuff muscles and/or tightening of the posterior joint capsule which may lead to glenohumeral joint dysfunction and impingement syndromes.

Data and Results:

Male

RIGHT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 101st	125	73	113
Top 25th %tile 101st	117	65	109
50th %tile 101st	110	58	103
Bottom 25th %tile 101st	104	52	97
Triathletes	112 ± 7	54 ± 9	110 ± 7
Athlete*	124	91	105
Clinical Range	90-110	50-65	100-120
101st	110 ± 13	59 ± 10	103 ± 9

LEFT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 101st	118	84	115
Top 25th %tile 101st	112	76	110
50th %tile 101st	105	67	104
Bottom 25th %tile 101st	97	58	100
Triathletes	109 ± 9	62 ± 10	111 ± 8
Athlete*	124	91	105
Clinical Range	90-110	50-65	100-120
101st	104 ± 12	67 ± 13	105 ± 9

*** Brown 1988**

Female

RIGHT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 101st	137	75	117
Top 25th %tile 101st	130	67	112
50th %tile 101st	120	60	107
Bottom 25th %tile 101st	111	54	103
Triathletes	123 ± 12	63 ± 16	121 ± 11
Athlete*	124	91	105
Clinical Range	90-110	50-65	100-120
101st	120 ± 16	61 ± 12	108 ± 7

LEFT

	External Rotation (degrees)	Internal Rotation (degrees)	PST (degrees)
Top 10th %tile 101st	128	89	118
Top 25th %tile 101st	121	79	115
50th %tile 101st	114	68	109
Bottom 25th %tile 101st	105	55	106
Triathletes	117 ± 14	75 ± 14	123 ± 11
Athlete*	124	91	105
Clinical Range	90-110	50-65	100-120
101st	113 ± 14	68 ± 15	110 ± 7

*** Brown 1988**

Summary: On average, for external rotation the male Soldiers demonstrated external rotation range of motion consistent with the male triathletes bilaterally, and had up to 16% and 12% less external rotation compared to the athletes and top 10th percentile of male Soldiers. On average, for internal rotation the male Soldiers demonstrated internal rotation range of motion consistent with the male triathletes bilaterally, and had up to 35% and 20% less internal rotation compared to the athletes and top 10th percentile of male Soldiers. On average, for posterior shoulder tightness the male Soldiers demonstrated posterior shoulder tightness consistent with the athletes, male triathletes, and top 10th percentile of male Soldiers bilaterally. Suboptimal shoulder external rotation, internal rotation and posterior shoulder tightness was demonstrated in up to 75%, 98%, and 13% of the male Soldiers respectively.

On average, for external rotation the female Soldiers demonstrated external rotation range of motion consistent with the athletes, and female triathletes bilaterally, and had up to 12% less external rotation compared to the top 10th percentile of female Soldiers. On average, for internal rotation the female Soldiers demonstrated internal rotation range of motion consistent with the female triathletes bilaterally, and had up to 33% and 23% less internal rotation compared to the athletes and top 10th percentile of female Soldiers. On average, for posterior shoulder tightness the female Soldiers demonstrated posterior shoulder tightness consistent with the athletes, female triathletes, and top 10th percentile of female

Soldiers bilaterally. Suboptimal shoulder external rotation and internal rotation was demonstrated in up to 44% and 94%, of the female Soldiers respectively.

Knee Flexion and Active Extension Flexibility

Testing methodology:
Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)
3 measures
Passive knee flexion and active knee extension
Average of 3 joint angles (°)

Purpose: Examine knee flexion and active extension flexibility

Background: Maintenance of appropriate flexibility between the quadriceps and hamstring muscle groups of the knee contributes to maximal force generation across the available range of motion while also providing for the dynamic stabilization and stiffness necessary for joint protection during demanding tasks involving the lower extremity. Deficits in flexibility in one or both of these muscle groups may contribute to acute or chronic injuries affecting the proper functioning of the knee and jeopardizing overall joint stability.

Data and Results:

Male

RIGHT

	Flexion (degrees)	Active Extension (degrees)
Top 10th %tile 101st	151	8
Top 25th %tile 101st	148	12
50th %tile 101st	144	18
Bottom 25th %tile 101st	140	25
Triathletes	15 ± 11	14 ± 10
Athlete*	--	34
Clinical Range	125-145	0-10
101st	143 ± 7	19 ± 9

LEFT

	Flexion (degrees)	Active Extension (degrees)
Top 10th %tile 101st	151	6
Top 25th %tile 101st	147	10
50th %tile 101st	142	16
Bottom 25th %tile 101st	139	24
Triathletes	5 ± 2	5 ± 1
Athlete*	--	34
Clinical Range	125-145	0-10
101st	142 ± 7	17 ± 10

***Miller 2011**

Female

RIGHT

	Flexion (degrees)	Active Extension (degrees)
Top 10th %tile 101st	158	2
Top 25th %tile 101st	152	5
50th %tile 101st	149	10
Bottom 25th %tile 101st	144	16
Triathletes	141 ± 8	12 ± 12
Athlete*	--	34
Clinical Range	125-145	0-10
101st	149 ± 6	11 ± 8

LEFT

	Flexion (degrees)	Active Extension (degrees)
Top 10th %tile 101st	156	1
Top 25th %tile 101st	151	4
50th %tile 101st	148	8
Bottom 25th %tile 101st	144	12
Triathletes	141 ± 7	13 ± 12
Athlete*	--	34
Clinical Range	125-145	0-10
101st	147 ± 6	9 ± 8

***Miller 2011**

Summary: On average, for knee flexion the male Soldiers demonstrated knee flexion range of motion consistent with the male triathletes and the top 10th percentile of male Soldiers. On average, for active knee extension the male Soldiers demonstrated up to 50% greater (smaller number indicates greater range of motion) active knee extension compared to the athletes, and up to and 240%, and 183% less active knee extension compared to the male triathletes and top 10th percentile of male Soldiers. Suboptimal active knee extension was demonstrated in up to 69%of the male Soldiers respectively.

On average, for knee flexion the female Soldiers demonstrated knee flexion range of motion consistent with the female triathletes and the top 10th percentile of female Soldiers. On average, for active knee extension the female Soldiers demonstrated up to 73% and 30% greater (smaller number indicates greater range of motion) active knee extension compared to the athletes and triathletes and up to , and 800% less than the top 10th percentile of female Soldiers. Suboptimal active knee extension was demonstrated in up to 31% of the female Soldiers respectively.

Hip Flexion and Extension Flexibility

Testing methodology:
Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)
3 measures
Passive hip flexion and extension
Average of 3 joint angles (°)

Purpose: Examine hip flexion and extension flexibility

Background: Hip musculature flexibility is essential for the mobility and generation of force necessary to perform all physical tasks involving the lower extremity. Flexibility deficits at the hip will negatively impact overall performance, contributing to altered kinematics and increased stresses on distal joints leading to acute and chronic injuries that threaten the stability of the lower extremity.

Data and Results:

Male

RIGHT

	Flexion (degrees)	Extension (degrees)
Top 10th %tile 101st	142	39
Top 25th %tile 101st	138	34
50th %tile 101st	134	30
Bottom 25th %tile 101st	129	25
Triathletes	138 ± 6	21 ± 8
Normative	130 ± 8	17 ± 6
Clinical Range	120-140	20-40
101st	133 ± 7	29 ± 8

LEFT

	Flexion (degrees)	Extension (degrees)
Top 10th %tile 101st	143	40
Top 25th %tile 101st	139	35
50th %tile 101st	134	30
Bottom 25th %tile 101st	130	25
Triathletes	137 ± 6	21 ± 6
Normative	130 ± 8	17 ± 6
Clinical Range	120-140	20-40
101st	133 ± 7	30 ± 8

***Soucie 2011**

Female

RIGHT

	Flexion (degrees)			Extension (degrees)		
Top 10th %tile 101st	144			43		
Top 25th %tile 101st	142			39		
50th %tile 101st	139			33		
Bottom 25th %tile 101st	135			29		
Triathletes	141	±	10	36	±	9
Normative	130	±	8	17	±	6
Clinical Range	120-140			20-40		
101st	136	±	17	34	±	7

LEFT

	Flexion (degrees)			Extension (degrees)		
Top 10th %tile 101st	145			44		
Top 25th %tile 101st	143			39		
50th %tile 101st	139			34		
Bottom 25th %tile 101st	134			30		
Triathletes	139	±	8	37	±	8
Normative	130	±	8	17	±	6
Clinical Range	120-140			20-40		
101st	136	±	16	34	±	7

***Soucie 2011**

Summary: On average, for hip flexion the male Soldiers demonstrated hip flexion range of motion consistent with a normal population, male triathletes and the top 10th percentile of male Soldiers. On average, for hip extension the male Soldiers demonstrated up to 76% and 42% greater hip extension compared to the normal population and triathletes, and up to 25% less hip extension compared to the top 10th percentile of male Soldiers.

On average, for hip flexion the female Soldiers demonstrated hip flexion range of motion consistent with a normal population, female triathletes and the top 10th percentile of female Soldiers. On average, for hip extension the female Soldiers demonstrated consistent with the female triathletes and up to 100% greater hip extension compared to the normal population, and up to 22% less hip extension compared to the top 10th percentile of female Soldiers.

Calf Flexibility

Testing methodology:
Saunders Digital Inclinometer (The Saunders Group, Chaska, MN)
3 measures
Active ankle dorsiflexion
Average of 3 joint angles (°)

Purpose: Examine ankle dorsiflexion flexibility

Background: Adequate flexibility of the calf musculature contributes to proper mechanical functioning of the knee and ankle joints as well as the generation of forces necessary for tasks such as running and jumping. Deficits in calf musculature flexibility will have a negative impact on overall physical performance and may contribute to acute and/or chronic injuries involving the knee and ankle.

Data and Results:

Male

	Right (degrees)	Left (degrees)
Top 10th %tile 101st	24	25
Top 25th %tile 101st	19	21
50th %tile 101st	16	16
Bottom 25th %tile 101st	11	12
Triathletes	12 ± 6	12 ± 6
Clinical Range	10-25	10-25
101st	16 ± 7	16 ± 7

Female

	Right (degrees)	Left (degrees)
Top 10th %tile 101st	23	23
Top 25th %tile 101st	19	20
50th %tile 101st	15	15
Bottom 25th %tile 101st	11	11
Triathletes	11 ± 6	10 ± 6
Clinical Range	10-25	10-25
101st	15 ± 6	15 ± 6

Summary: On average, for ankle dorsiflexion the male Soldiers demonstrated up to 33% greater ankle dorsiflexion compared to the male triathletes, and up to 36% less ankle dorsiflexion compared to the top 10th percentile of male Soldiers.

On average, for ankle dorsiflexion the female Soldiers demonstrated up to 50% greater ankle dorsiflexion compared to the female triathletes, and up to 35% less ankle dorsiflexion compared to the top 10th percentile of female Soldiers.

Torso Right and Left Rotation Flexibility

Testing methodology:
Biodex System 3 isokinetic dynamometer (Biodex Medical, Shirley, NY)
3 repetitions to right and left maximum rotation
Average of 3 joint angles

Purpose: Examine torso rotation flexibility

Background: Adequate torso rotation flexibility is important for core stabilization and the generation of forces necessary to respond to demanding physical tasks. Deficits here contribute to altered spinal mobility that may lead to injury to the lumbar spine and a decrease in efficiency of physical tasks involving the upper and lower extremities.

Data and Results:

Male

	Right Rotation (degrees)	Left Rotation (degrees)
Top 10th %tile 101st	84	79
Top 25th %tile 101st	77	73
50th %tile 101st	70	65
Bottom 25th %tile 101st	64	58
Triathletes	72 ± 9	70 ± 12
Clinical Range	60-80	60-80
101st	70 ± 11	66 ± 11

Female

	Right Rotation (degrees)	Left Rotation (degrees)
Top 10th %tile 101st	87	85
Top 25th %tile 101st	80	75
50th %tile 101st	73	69
Bottom 25th %tile 101st	64	59
Triathletes	82 ± 12	76 ± 11
Clinical Range	60-80	60-80
101st	73 ± 11	68 ± 11

Summary: On average, for trunk rotation the male Soldiers demonstrated trunk rotation range of motion consistent with the male triathletes and up to 17% less compared to the top 10th percentile of male Soldiers bilaterally.

On average, for trunk rotation the female Soldiers demonstrated trunk rotation range of motion up to 11% and 20% less than female triathletes and the top 10th percentile of female Soldiers respectively.

Balance

Balance: Variability of Ground Reaction Forces (GRF) – Eyes Open

Testing methodology:
Kistler force plate
3 measures of movement variability
Average of 3 trials

Purpose: Examine postural stability through single-leg balance

Background: Accurate sensory information, as measured through single-leg balance testing, is essential to the performance of complex motor patterns, maintaining joint stability, and preventing injury. Deficits in this area may indicate a greater risk for ankle and knee injury.

Data and Results:

EYES OPEN – RIGHT AND LEFT LEG

Male

	GRF-CU Right (N)	GRF-CU Left (N)
Top 10th %tile 101st	4.06	3.95
Top 25th %tile 101st	4.95	4.93
50th %tile 101st	6.24	6.35
Bottom 25th %tile 101st	7.64	7.61
Triathletes	7.18 ± 2.62	7.91 ± 3.23
101st	6.56 ± 2.80	6.57 ± 2.92

Female

	GRF-CU Right (N)	GRF-CU Left (N)
Top 10th %tile 101st	3.52	3.17
Top 25th %tile 101st	3.68	3.75
50th %tile 101st	4.29	4.39
Bottom 25th %tile 101st	5.53	5.57
Triathletes	5.20 ± 3.07	4.30 ± 1.56
101st	5.99 ± 11.57	4.84 ± 1.96

Summary: On average, the male Soldiers were within normal limits as compared to the triathlete model and 61% worse when compared to the top 10th percentile of male Soldiers for eyes open balance. On average, the female Soldiers were also within normal limits as compared to the triathlete model and 70% worse when compared to the top 10th percentile of female Soldiers for eyes open balance.

Balance: Variability of Ground Reaction Forces (GRF) – Eyes Closed

Testing methodology:
Kistler force plate
3 measures of movement variability
Average of 3 trials

Purpose: Examine postural stability through single-leg balance

Background: Accurate sensory information, as measured through single-leg balance testing, is essential to the performance of complex motor patterns, maintaining joint stability, and preventing injury. Eyes closed testing increases the reliance on other somatosensory input (vestibular, sensorimotor) to simulate nighttime maneuvers. Deficits in this area may indicate a greater risk for ankle and knee injury.

Data and Results:

EYES CLOSED – RIGHT AND LEFT LEG

Male

	GRF-CU Right (N)	GRF-CU Left (N)
Top 10th %tile 101st	9.62	9.10
Top 25th %tile 101st	12.09	11.36
50th %tile 101st	16.85	16.25
Bottom 25th %tile 101st	22.32	23.08
Triathletes	19.18 ± 8.23	24.38 ± 16.24
101st	19.81 ± 13.60	19.46 ± 13.59

Female

	GRF-CU Right (N)	GRF-CU Left (N)
Top 10th %tile 101st	6.65	7.06
Top 25th %tile 101st	7.64	9.33
50th %tile 101st	11.32	12.22
Bottom 25th %tile 101st	15.01	16.13
Triathletes	14.21 ± 8.48	14.98 ± 8.31
101st	12.04 ± 6.19	13.63 ± 8.38

Summary: On average, the male Soldiers were within normal limits compared to the triathlete model and 106% worse when compared to the top 10th percentile of male Soldiers for eyes closed balance. On average, the female Soldiers were within normal limits when compared to the triathlete model and 93% worse than the top 10th percentile of female Soldiers for eyes closed balance.

Physiology

Body Composition

Testing methodology:
BODPOD body composition tracking system

Purpose: Examine body composition (fat mass/lean mass)

Background: Optimal performance can further be improved by increasing the lean tissue mass (muscle) within the body, ultimately increasing strength and reducing the effects of fatigue due to excessive body mass and body fat. Similarly, too little body fat has also been shown to negatively affect athletic performance as low essential fat stores interfere with the normal physiological processes of the body, increase the risk of injury, and prolong injury recovery. Low body fat stores may decrease the available fuel to sustain prolonged training and combat missions. Additionally, the varying terrains and environmental conditions further support the importance of optimal body composition distribution. From a long-term health prospective, less body fat will decrease the risk of hypokinetic diseases (i.e. cardiovascular disease, diabetes, hypertension, hypercholesterolemia).

Data and Results:

Male

	Body Fat (%)	Height (inches)	Weight (pounds)
Top 10th %tile 101st	11.0	--	--
Top 25th %tile 101st	15.1	--	--
50th %tile 101st	20.2	--	--
Bottom 25th %tile 101st	25.2	--	--
Triathletes	12.31 ± 4.37	--	--
Athlete*	15.42	--	--
101st	20.31 ± 7.30	69.74 ± 2.81	184.54 ± 27.40

***NMRL Database Athletes**

Female

	Body Fat (%)	Height (inches)	Weight (pounds)
Top 10th %tile 101st	20.0	--	--
Top 25th %tile 101st	22.5	--	--
50th %tile 101st	28.1	--	--
Bottom 25th %tile 101st	31.0	--	--
Triathletes	17.37 ± 4.38	--	--
101st	27.17 ± 5.79	64.69 ± 2.59	143.01 ± 22.01

Summary: Summary: The average body fat for male Soldiers was 31.7% higher than the athlete model and 84.6% higher than the top 10th percentile of male Soldiers. Approximately 84% of the male Soldiers were above the athlete model of 13% body fat (75% above 15% BF). The average body fat for female

Soldiers was 564% higher than the athlete model and 35.8% higher than the top 10th percentile of female Soldiers. Approximately 91% of the female Soldiers were above the athlete model of 17% body fat.

Particular concern should continue to be focused on the 50% of male Soldiers with body fat over 20% and 30% of female Soldiers with body fat over 30% as there is a higher propensity for diabetes, high cholesterol, high blood pressure, and heart disease. Additionally 27% of Soldiers did not meet the Army Weight Screening Table and Maximal Allowable Body Fat Standards for gender and age. Based on preliminary results, an overall decrease of body fat is necessary and can be achieved by modifying nutritional intake and increasing resistance training to promote anabolic activity of muscle and catabolic activity of fat.

Anaerobic Power/Capacity

Testing methodology:
Velotron cycling ergometer (RacerMate, Inc., Seattle, WA)
Measuring range: 5 to 2000 watts
Accuracy: +/- 1.5%
Repeatability: +/- 0.2 % or better

Purpose: Examine anaerobic power/capacity

Background: The development of lower extremity overuse injuries has been associated with low levels of physical fitness. Suboptimal levels of anaerobic power, along with other diminished physiological characteristics, as a result of non-scientifically structured training have been directly related to an increased risk of injury and impaired performance. Anaerobic power and capacity are critical when high intensity, high stress bouts are followed by the need for tactical performance (gun firing). Anaerobic power represents the power generated between 0-5 seconds and anaerobic capacity represents the sustainable power between 0-30 seconds. Improving anaerobic power capacity will allow for a faster metabolic recovery from performing such high intensity, short duration activities without negatively influencing overall performance.

Data and Results:

Male

	Anaerobic Power (W/kg)	Anaerobic Capacity (W/kg)
Top 10th %tile 101st	15.90	8.90
Top 25th %tile 101st	14.58	8.50
50th %tile 101st	13.50	7.90
Bottom 25th %tile 101st	12.00	7.20
Triathletes	13.75 ± 1.05	9.25 ± 0.70
Athlete*	16.86	10.45
101st	13.39 ± 2.00	7.77 ± 1.02

***NMRL Database**

Female

	Anaerobic Power (W/kg)	Anaerobic Capacity (W/kg)
Top 10th %tile 101st	11.62	6.90
Top 25th %tile 101st	10.10	6.60
50th %tile 101st	9.00	6.10
Bottom 25th %tile 101st	8.30	5.40
Triathletes	11.92 ± 1.43	8.37 ± 0.80
101st	9.34 ± 1.66	6.01 ± 0.79

***NMRL Database**

Summary: The average male Soldier is 20.6% less than the athlete model for anaerobic power and 25.6% less than the athlete model for anaerobic capacity. The average male Soldier is 15.8% less than the top 10th percentile for anaerobic power and 12.7% less than the top 10th percentile for anaerobic capacity. The average female Soldier is 19.6% less than the top 10th percentile for anaerobic power and 12.9% less than the top 10th percentile for anaerobic capacity.

Aerobic Capacity/Lactate Threshold

Testing methodology:
Viasys Oxycon Mobile portable ergospirometry system
Arkray LactatePro blood lactate test meter

Purpose: Examine cardiorespiratory endurance (VO2max)

Background: The development of overuse injuries has been associated with low levels of physical fitness. A significant relationship has been reported between less aerobically fit Soldiers and increased injuries compared to those who are more fit. Suboptimal levels of maximal oxygen consumption and lactate threshold have been directly related to an increased risk of injury and impaired performance as premature fatigue results. Improvements in maximal oxygen consumption and lactate threshold with training will permit workout levels at higher intensities for longer durations without the accumulation of blood lactate to impair performance, while making the Soldier more fatigue resistant.

Data and Results:

Male

	VO2 max (ml/kg/min)	VO2 @ LT (ml/kg/min)	VO2 @ LT (% VO2 max)
Top 10th %tile 101st	56.20	43.10	87.80
Top 25th %tile 101st	52.05	37.90	82.70
50th %tile 101st	47.00	34.10	77.20
Bottom 25th %tile 101st	42.20	31.34	71.42
Triathletes	69.76 ± 7.29	58.20 ± 7.30	83.66 ± 8.52
101st	47.27 ± 7.01	38.80 ± 6.52	81.95 ± 8.90

Female

	VO2 max (ml/kg/min)	VO2 @ LT (ml/kg/min)	VO2 @ LT (% VO2 max)
Top 10th %tile 101st	47.00	37.00	90.00
Top 25th %tile 101st	45.00	32.50	83.50
50th %tile 101st	40.00	29.00	78.00
Bottom 25th %tile 101st	35.75	27.00	73.40
Triathletes	61.17 ± 5.42	54.03 ± 5.91	88.38 ± 6.56
101st	40.00 ± 5.61	33.38 ± 5.35	82.62 ± 12.83

Summary: Overall, the male Soldiers were 32.2% below the athlete model and 15.9% below the top 10th percentile for VO2 max. Particular concern should focus on the 65.5% of male Soldiers with a VO2 max below 50 ml/kg/min. As a function of VO2 max, lactate threshold for the male Soldiers was 2% less than the athlete model and 6.7% less than the top 10th percentile. Overall, the female Soldiers were 34.6% below the athlete model and 14.9% below the top 10th percentile for VO2 max. As a function of VO2 max, lactate threshold for the female Soldiers was 6.5% less than the athlete model and 8.2% less than the top 10th percentile.

Biomechanics

Hip Kinematics: Two-Legged Stop-Jump

Testing methodology:
3D optical capture system (Vicon, Centennial, CO)

Purpose:
Examine hip flexion and abduction/adduction at initial contact

Background:
The hip and surrounding musculature play an essential role in lower extremity dynamic stability. Landing with greater flexion at the hip will allow for more efficient use of the strong muscles of the hip and subsequent absorption of joint forces. Landing with the hip in an adducted position will increase the chance of a dangerous landing position at the knee.

Data and Results:

Male

RIGHT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 101st	57.5	5 to -5
Top 25th %tile 101st	50.6	10 to -10
50th %tile 101st	42.5	15 to -15
Bottom 25th %tile 101st	34.7	20 to -20
Triathletes	51.1 ± 13.2	-2.6 ± 3.5
101st	42.6 ± 11.5	-3.6 ± 4.1

LEFT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 101st	57.3	5 to -5
Top 25th %tile 101st	51.7	10 to -10
50th %tile 101st	43.4	15 to -15
Bottom 25th %tile 101st	35.0	20 to -20
Triathletes	54.4 ± 13.2	-2.0 ± 4.2
101st	43.4 ± 11.4	-3.8 ± 4.1

Female

RIGHT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 101st	61.2	5 to -5
Top 25th %tile 101st	54.0	10 to -10
50th %tile 101st	43.3	15 to -15
Bottom 25th %tile 101st	35.3	20 to -20
Triathletes	49.6 ± 11.7	-2.6 ± 3.9
101st	45.4 ± 11.8	-2.2 ± 4.0

LEFT

	Hip Flexion @ Initial Contact (degrees)	Hip Abduction @ Initial Contact (degrees)
Top 10th %tile 101st	59.7	5 to -5
Top 25th %tile 101st	53.8	10 to -10
50th %tile 101st	45.3	15 to -15
Bottom 25th %tile 101st	36.7	20 to -20
Triathletes	50.2 ± 11.2	-5.0 ± 3.0
101st	45.4 ± 12.3	-3.0 ± 5.4

Summary: The majority of male and female Soldiers landed with a flexed and abducted position at the hip, potentially a safe landing. Approximately 76% of male Soldiers landed with less hip flexion than the athletes and 37% were outside the clinical range, defined at -5 to 5, of hip abduction/adduction. Approximately 60% of female Soldiers landed with less hip flexion than the athletes and 29% outside the clinical range of hip abduction/adduction.

Knee Kinematics: Two-Legged Stop-Jump

Testing methodology:
3D optical capture system (Vicon, Centennial, CO)

Purpose:
Examine maximum knee flexion, knee flexion/valgus at initial contact

Background:
Flexing the knee at landing and throughout dynamic tasks is essential to absorbing the dangerous landing forces experienced throughout the lower extremity. Inadequate flexion combined with a valgus knee angle can increase the strain on knee ligaments which can lead to tissue failure and injury.

Data and Results:

Male

RIGHT

	Knee Flexion @ Initial Contact (degrees)	Knee Valgus @ Initial Contact (degrees)	Maximum Knee Flexion (degrees)
Top 10th %tile 101st	37.3	5 to -5	109.4
Top 25th %tile 101st	31.4	10 to -10	100.0
50th %tile 101st	26.5	15 to -15	90.9
Bottom 25th %tile 101st	20.3	20 to -20	82.0
Triathletes	29.9 ± 8.7	5.6 ± 3.8	82.4 ± 11.9
101st	26.5 ± 8.3	4.1 ± 6.6	92.0 ± 15.2

LEFT

	Knee Flexion @ Initial Contact (degrees)	Knee Valgus @ Initial Contact (degrees)	Maximum Knee Flexion (degrees)
Top 10th %tile 101st	38.4	5 to -5	109.0
Top 25th %tile 101st	32.9	10 to -10	99.5
50th %tile 101st	27.3	15 to -15	92.0
Bottom 25th %tile 101st	22.2	20 to -20	82.7
Triathletes	34.8 ± 9.5	6.2 ± 9.1	84.8 ± 8.3
101st	27.6 ± 8.3	4.3 ± 6.7	92.1 ± 14.6

Female

RIGHT

	Knee Flexion @ Initial Contact (degrees)			Knee Valgus @ Initial Contact (degrees)			Maximum Knee Flexion (degrees)		
Top 10th %tile 101st	38.5			5 to -5			107.5		
Top 25th %tile 101st	32.4			10 to -10			97.7		
50th %tile 101st	25.5			15 to -15			89.4		
Bottom 25th %tile 101st	20.4			20 to -20			81.9		
Triathletes	33.7	±	7.8	-4.6	±	6.7	89.6	±	9.6
101st	26.9	±	8.2	-1.8	±	5.5	89.8	±	14.0

LEFT

	Knee Flexion @ Initial Contact (degrees)			Knee Valgus @ Initial Contact (degrees)			Maximum Knee Flexion (degrees)		
Top 10th %tile 101st	37.6			5 to -5			106.1		
Top 25th %tile 101st	32.7			10 to -10			95.9		
50th %tile 101st	27.0			15 to -15			88.8		
Bottom 25th %tile 101st	22.2			20 to -20			82.5		
Triathletes	34.9	±	8.2	-2.6	±	3.7	92.2	±	11.7
101st	27.2	±	8.3	-1.7	±	5.9	88.0	±	14.9

Summary: Most of the Soldiers landed with the knees flexed and flexed the knees to an appropriate position for the task. Unfortunately, 50% of male Soldiers and 43% of female Soldiers landed outside the clinical range, defined at -5 to 5, of valgus/varus which can increase the risk of ligamentous injury.

Ground Reaction Forces: Two-Legged Stop-Jump

Testing methodology:
Kistler force plates (Kistler Corp, Worthington, OH)
Collected at 1200 Hz

Purpose:
Examine peak vertical ground reaction forces

Background:
Vertical ground reaction forces directly correlate with high joint forces. Individuals who are able to decrease landing forces through modified landing strategies should be able to mitigate these forces and reduce their risk of injury.

Data and Results:

Male

RIGHT

	Peak Vertical GRF (%BW)
Top 10th %tile 101st	135.9
Top 25th %tile 101st	160.3
50th %tile 101st	189.0
Bottom 25th %tile 101st	233.3
Triathletes	210.8 ± 48.1
101st	200.7 ± 57.0

LEFT

	Peak Vertical GRF (%BW)
Top 10th %tile 101st	135.9
Top 25th %tile 101st	154.4
50th %tile 101st	185.0
Bottom 25th %tile 101st	225.3
Triathletes	224.3 ± 63.2
101st	195.0 ± 54.5

Female

RIGHT

	Peak Vertical GRF (%BW)
Top 10th %tile 101st	137.4
Top 25th %tile 101st	154.3
50th %tile 101st	184.4
Bottom 25th %tile 101st	216.1
Triathletes	198.6 ± 65.3
101st	196.9 ± 60.3

LEFT

	Peak Vertical GRF (%BW)
Top 10th %tile 101st	126.6
Top 25th %tile 101st	140.8
50th %tile 101st	180.9
Bottom 25th %tile 101st	230.6
Triathletes	184.0 ± 40.5
101st	192.3 ± 66.0

Summary: Despite average values less than the threshold (250 %BW), testing revealed that approximately 18% of the male Soldiers and 14% of the female Soldiers landed with peak vertical ground reaction forces greater than the threshold value. Combined with poor knee extension and flexion strength and increased knee valgus position, the Soldiers are in a more likely position for knee injury during landing activities.

Load Carriage Assessment/Visual Impairment

Lower extremity musculoskeletal injury is one of the most common injuries in the US Armed Forces. Landing position and decreased static postural stability has been shown to be risk factors for lower extremity musculoskeletal injury. Limited research has investigated the effect of military load carriage on landing position and postural stability.

Measures of knee joint position, ground reaction forces, anterior/posterior, medial/lateral, and vertical static postural stability and dynamic postural stability during a functional landing task were assessed with and without load. Wearing load resulted in changes to knee landing position of 8%, greater ground reaction forces (normalized to body mass and load) of 25%, decreased static and dynamic postural stability 7-10% relative to the non-load conditions.

Preliminary data from another study has also demonstrated similar effects with additional load. The addition of load increased the peak VGRF during gait by 18.7% BW and the time to exhaustion during a VO2 max test decreased by 50% and caloric expenditure increased by 20%.

These alterations attributed to carrying additional loads may increase the risk of lower extremity injuries and ultimately impact physical and tactical readiness. Gradually integrating additional load and dynamic stability tasks into physical training is recommended to promote kinematic adaptations and greater postural stability during tactical demands.

Asymmetry

Side-to-side (S-S) symmetry of lower extremity (LE) muscle strength is important for preventing between-limb compensations that overload one side and increase injury risk. As such, S-S comparisons in LE strength are frequently made in injury prevention and rehabilitation contexts. Past work consistently shows S-S LE strength differences <10% are normal in athletes. However, S-S LE strength differences in large military samples have not been previously reported. Considering the healthcare burden of unintentional musculoskeletal injuries, characterizing the S-S LE strength differences in Soldiers will give data of the frequency of potentially dangerous S-S muscle imbalance. This data can then be used to screen for future risk of new LE injury or re-injury.

An isokinetic dynamometer measured concentric quadriceps (QUAD) and hamstring (HAM) mean peak torque (Nm/kg, 5 reciprocal repetitions, 60°/sec), and isometric hip abductor (ABD) mean peak force (N/kg, 3 reciprocal repetitions, 5 sec/effort). A handheld dynamometer measured isometric ankle eversion (EV) and inversion (INV) mean peak force (kg, 3 repetitions, 5 secs/effort). Counts were made of Soldiers with S-S differences >10% (designated 'suprathreshold'(ST)) and proportions calculated.

For QUAD and HAM strength, 41% had S-S differences >10% (ST range=11-50%). For ABD strength, 38% had S-S differences >10% (ST range=11-53%). For EV strength, 34% had S-S differences >10% (ST range=11-37.5%). For INV strength, 37% has S-S differences >10% (ST range=11-40%).

A large proportion of Soldiers (>33%) had S-S leg strength differences >10% (maximum S-S difference=53%). Consideration should be given to correction of S-S imbalances via targeted training programs. Such intervention may contribute to reducing the risk of sustaining new unintentional LE injury or re-injury, and enhance Soldiers' ability to safely and effectively execute mission essential tasks.

Aviator Data Collection

Helicopter pilots face long hours of flight missions and physical stress. Several epidemiology studies have revealed a high prevalence of neck pain (NP) and low back pain (LBP) in military helicopter pilots.1-5 Van den Oord et al.3 evaluated 113 helicopter pilots of the Royal Netherlands Air Force and Navy and reported that one-year prevalence of any NP was 43%, and over 20% had regular or continuous neck pain. One-year prevalence of continuous shoulder pain, thoracic pain, and LBP were 7%, 13%, and 26%, respectively. In addition, the authors reported that female pilots suffered more NP than their male counterparts, suggesting further research on gender differences on neck pain.3 Ang et al.4 evaluated 127 Swedish helicopter pilots and reported three-month prevalence of NP was 57%, and over 30% had frequent pain. Three-month prevalence of shoulder pain, thoracic pain, and LBP were 35%, 16%, and 46%, respectively.4 Thomae et al.1 analyzed surveys on LBP prevalence from 131 Australian military helicopter pilots and reported that over 80% of pilots had discomfort or pain. Similarly, Bridger et al.5 analyzed surveys on NP and LBP prevalence from 185 Royal Navy helicopter pilots and reported the 12-month prevalence of NP and LBP was 48% and 80%, respectively.

Van den Oord et al.3 analyzed helicopter pilots with continuous NP (pain group: 22 pilots) and helicopter pilots without continuous NP (non-pain group: 91 pilots) on several factors: work-related, personal demographics, and health-related. The pain group had significantly more total flying hours (career flying hours as well as the flying hours in the previous year) than the non-pain group while a total flying hours with night vision goggle (NVG) was not significantly different between groups.3 The pain group reported significantly higher prevalence of continuous shoulder pain and upper back pain than the non-pain group while the prevalence of continuous LBP was not significant between groups.3 Ang et al.4 reported that the use of NVG, history of NP, incidence of shoulder pain, thoracic pain, or LBP was identified as risk indicators of neck pain. Interestingly, the authors reported that muscle strength training of 1+ hour per week was associated with lower NP (relative risk = 0.5-0.9).4

Thomae et al.1 reported that past back injury was a significant predictor of LBP while other variables (age, education, BMI, posture, and flying hours) did not show a significant association with LBP. Bridger et al.5 reported no association between LBP and psychosocial variables such as job satisfaction, mental stress, and social support at work. Instead, a self-reported trunk forward flexed posture was commonly reported by pilots with back pain.5

Despite a high prevalence of NP and LBP in military helicopter pilots, there have been few studies evaluating musculoskeletal characteristics of aviators. Van den Oord et al.6 evaluated neck strength, cervical spine range of motion, and joint position sense on 129 helicopter crew (78 pilots and 39 aircrew) and compared between those with and without NP. The authors reported that there was a trend toward lower strength and cervical range of motion.6 Ang et al.7 evaluated neck strength on two groups of helicopter pilots (15 pilots with NP and 15 pilots without NP) and reported that there was no significant difference between the groups.

The current investigation on helicopter pilots adds insight to the phases that have already been completed, and can integrate information based on a more specific subset of the 101st Airborne Soldiers. The current investigation had three specific aims: the first aim was to survey a prevalence of NP and LBP based on MOS and gender; the second aim was to investigate the cervical spine, posterior shoulder, and trunk musculoskeletal characteristics and compare between pilots with and without a history of previous NP/LBP; and the third aim was to compare between genders. This investigation is clinical significant as it would identify ‘at risk’ Soldiers with specific MOS or gender and help medical community to provide an intervention for those who possess suboptimal musculoskeletal characteristics.

Testing Overview:

Injury Data Collection

The process of determining specific injury data related to NP and LBP included the implementation of several questionnaires. Each subject was interviewed by one of the researchers included in the study and the history of neck or low back pain within the past 12 months was established. This study utilized questionnaires that had already been developed; the Neck Disability Index (NDI) and Modified Oswestry Low Back Pain Disability Questionnaire (OSW) were used to describe their functional capacity of activities of daily living at the time of the worst pain episode within the past 12 months. The pain intensity (in a scale of 0-10 visual analog scale (VAS)) and pain duration (in days) at the time of the worst pain episode within the 12 months as well as dispositions after the episode were also asked.

Strength Data Collection

Trunk strength testing data was collected using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY) to assess average peak torque to body weight for the left/right torso rotation and flexion/extension. Subjects were positioned and stabilized by the manufacturer's guidelines to ensure proper alignment for testing and to restrict accessory movements. Subjects were asked to perform 5 left/right torso rotation and 5 flex/extension concentric-concentric repetitions at 60º/sec. Three practice trials preceded actual testing to ensure free movement, proper warm-up, and comfort of the subject throughout the range of motion. Variables included average peak torque normalized to body weight in flexion, extension, right and left rotation.

Cervical isometric strength was collected using a Lafayette Manual Muscle Testing System (Lafayette Instruments, Lafayette IN) to assess cervical flexion, extension, right lateral flexion, and left lateral flexion. Subjects were positioned and stabilized utilizing standard manual muscle testing positions to ensure proper alignment for testing and to restrict accessory movements. Subjects were asked to perform 3 maximum voluntary isometric contractions in each direction. Three practice trials preceded actual testing to ensure proper warm-up and comfort. Variables included peak force normalized to body weight in cervical flexion, extension, right lateral flexion, and left lateral flexion.

Flexibility Data Collection

Flexibility measurements of the cervical and forward head posture were assessed using the CROM device. Subjects were positioned and stabilized by the manufacturer's guidelines to ensure proper alignment for testing and to restrict accessory movements. Subjects were asked to move their neck in each direction (flexion, extension, right lateral flexion, left lateral flexion, right rotation, left rotation, and forward head posture) three times. Three practice trials preceded actual testing to ensure proper warm-up and comfort. Variables included average range of motion in flexion, extension, right lateral flexion, left lateral flexion, right rotation, left rotation, and forward head posture.

Flexibility measurements of the lumbar spine were assessed using an inclinometer. Subjects were positioned and stabilized by the manufacturer's guidelines to ensure proper alignment for testing and to restrict accessory movements. Subjects were asked to move their back in each direction (flexion, extension, right lateral flexion, left lateral flexion, right rotation, and left rotation) three times. Three practice trials preceded actual testing to ensure proper warm-up and comfort. Variables included average range of motion in lumbar flexion, extension, right lateral flexion, left lateral flexion, right rotation, and left rotation.

Proprioception Data Collection

Proprioception measurements of the cervical spine were assessed with the Vicon 3D motion capture system (Vicon Motion Systems and Peak Performance Inc., Oxford, United Kingdom). Retroreflective markers were placed on the skin at specific bony landmarks. Bony landmarks included the spinous

processes of C7 and T8, the jugular notch and xiphoid process, as well as on a headband immediately above the sphenoid bones (temples) and parietal bones of the skull.
Cervical spine proprioception was assessed using active joint position sense (AJPS) tasks. Subjects were blindfolded on a firm chair with back-support, with the hips and knees at 90° flexion and the feet hip-width apart. Subjects' arms were supported so that the shoulder girdle and upper arm was passively elevated one inch from the seated anatomical position in order to offload tension from neck-shoulder myofascial and neurovascular structures. During trial data collection, subjects sat in the head-on-trunk anatomical position and instructed to actively acquire cervical left and right rotation target angles of 30° and 60° - these angles were determined by the Testers using real-time visual feedback from the Vicon system. Each target angle was actively maintained for five seconds, after which subjects were instructed to return to the head-on-trunk anatomical position. Subjects were then instructed to actively re-position their head as closely as possible to the initial active target position. Five active re-positioning trials were performed for each direction and each target angle (a total of 20 trials). The test order with regard to direction and target angle was randomized.

Statistical Analyses

For the first aim, a prevalence rate of NP and LBP was calculated by dividing a total number of Soldiers with a history by a total number of Soldiers for each MOS (pilots, aircrew, and non-aircrew) and gender (males vs. females). An odds ratio (OR) and 95% confidence interval (95%CI) were used to compare between groups. For the second and third aims, paired t-tests or Wilcoxon signed rank tests were used to compare musculoskeletal characteristics between groups.

Results

Prevalence of NP and LBP by MOS and Gender
A total of 183 Soldiers from three different MOSs voluntarily consented to participate in the study: 123 pilots (115 males / 8 females, age: 32.3 ± 6.2 years, height: 176.9 ± 7.9 cm, weight: 82.6 ± 12.2 kg), 28 aircrew (26 males / 2 females, age: 29.1 ± 5.8 years, height: 175.3 ± 9.4 cm, weight: 80.4 ± 10.7 kg), and 32 non-aircrew (25males / 7females, age: 26.0 ± 5.0 years, height: 173.9 ± 8.7 cm, weight: 79.2 ± 14.2 kg).

Self-reported pain questionnaires showed a 12- month prevalence of NP/LBP to be 30.1%/56.1%, 17.9%/ 6.4%, and 12.5%/28.1% for the pilots, aircrew, and non-aircrew, respectively. The pilots had a significantly higher prevalence of NP and LBP compared to the non-aircrew ($p = 0.04$, OR = 3.01, 95%CI = 0.99-9.20 and $p = 0.01$, OR = 3.27, 95%CI = 1.40-7.63, respectively). There were no differences between the pilots and the aircrew and between the aircrew and the non-aircrew on the prevalence of NP and LBP. Pilots were significantly older than aircrew and non-aircrew ($p < 0.05$). Pain characteristics for NP/LBP were as follows: VAS: 4.1 / 5.1, duration: 1.7 / 2.6 days, NDI: 16.5%, OSW: 17.5%, job-duty interference: 19.6%/12.1%, leisure interference: 23.9%/35.2%, and medical leave: 2.2%/6.6%.
Of 183 Soldiers, there were 166 males (age: 30.8±6.6 years, height: 177.4 ± 7.2 cm, weight: 83.3 ± 11.3 kg) and 17 females (age: 29.9 ± 4.2 years, height: 163.5 ± 8.0 cm, weight: 65.8 ± 11.4 kg). Self-reported pain questionnaires showed a 12-month prevalence of NP / LBP to be 24.7%/48.8% and 29.4%/58.8% for males and females, respectively. There were no significant differences between genders on the prevalence of NP and LBP.

Pilots with and without a History of NP Comparison

Pilots with a 12-month history of self-reported NP (28 males, age: 34.8 ± 6.4 years, height: 176.8 ± 7.0 cm, weight: 84.3 ± 11.3 kg) were matched based on gender/age (± 5 years) with subjects without a 12-month history of NP (28 males, age: 34.4 ± 6.0 years, height: 177.2 ± 8.3 cm, weight: 83.0 ± 11.8 kg). A comparison of neck strength, flexibility, posture and proprioception was performed between groups. Subjects with a history of NP had significantly less neck flexibility in flexion-extension (NP group: 120.8 ± 15.6°, non-NP group: 127.3 ± 9.2°), lateral flexion (NP group: 98.8 ± 14.5°, non-NP group: 106.2 ± 17.7°), and rotation (NP group: 136.2 ± 17.7°, non-NP group: 145.8 ± 13.6°) compared to subjects without a history of NP ($p < 0.05$).

Pilots with and without a History of LBP Comparison

Pilots with a self-reported history of LBP (29 males / 2 females, age: 31.5 ± 5.9 years, height: 177.1 ± 6.3cm, weight: 84.4 ± 11.3kg, total flight-hours: 1293 ± 1317 hours) were matched based on gender/age (± 5years) and total flight hours (± 500 hours) with subjects with no self-reported history of LBP (29 males/2 females, age: 31.5 ± 5.9 years, height: 176.9 ± 8.8 cm, weight: 82.9 ± 14.6 kg, total flight-hours: 1291 ± 1312 hours) and a comparison of trunk and hip strength and flexibility was conducted. The LBP group demonstrated significantly weaker trunk extension strength (LBP: 345.5 ± 78.1 %BM, non-LBP: 404.5 ± 66.0 %BM, $p = 0.004$). The LBP group had significantly less trunk lateral flexion right (LBP: 21.5 ± 4.1°, non-LBP: 26.4 ± 4.6°, $p < 0.001$) and left (LBP: 23.0 ± 4.4°, non-LBP: 26.8 ± 4.7°, $p = 0.005$) and right rotation flexibility (LBP: 9.4 ± 3.2°, non-LBP: 11.4 ± 3.9°, $p = 0.043$).

Gender Comparison

A comparison of neck strength, flexibility, posture and proprioception was also conducted based on gender. A total of 12 female Soldiers (age: 29.8 ± 4.7 years, height: 164.5 ± 9.2 cm, weight: 68.7 ± 3.6 kg) were matched to 12 male Soldiers (age: 29.2 ± 3.9 years, height: 175.2 ± 5.6 cm, weight: 82.1 ± 9.8 kg) based on age (± 3 years) and MOS. All Soldiers were free of self-reported NP and LBP. Female Soldiers demonstrated significantly less strength across all measurements ($p < 0.05$). Female Soldiers also demonstrated significant increases in cervical rotation range of motion (females: 80.5 ± 6.2°, males: 74.3 ± 4.8°, $p = 0.013$) and significant decreases in forward head posture (females: 20.5 ± 1.5 cm, males: 22.2 ± 1.4 cm, $p = 0.015$), right shoulder posture (females: 14.4 ± 2.7 cm, males: 17.1 ± 2.7 cm, $p = 0.009$), and left shoulder posture (females: 13.7 ± 2.3 cm, males: 15.6 ± 2.3 cm, $p = 0.026$).

Conclusions

The current study investigated a prevalence of NP and LBP among different MOS and gender and further elucidated modifiable musculoskeletal factors that were associated with pilots with a history of NP and LBP. Although the results highlighted suboptimal musculoskeletal characteristics, long-term effects of rotary engine (noice and vibration) and a prolonged flight on other modifiable factors such as vestibular, neurocognitive, and neuromuscular systems were largely unknown. It is a potential area to explore in the future to further advance preventative strategies for Soldiers with NP and LBP and enhance force readiness.

ETAP Integration

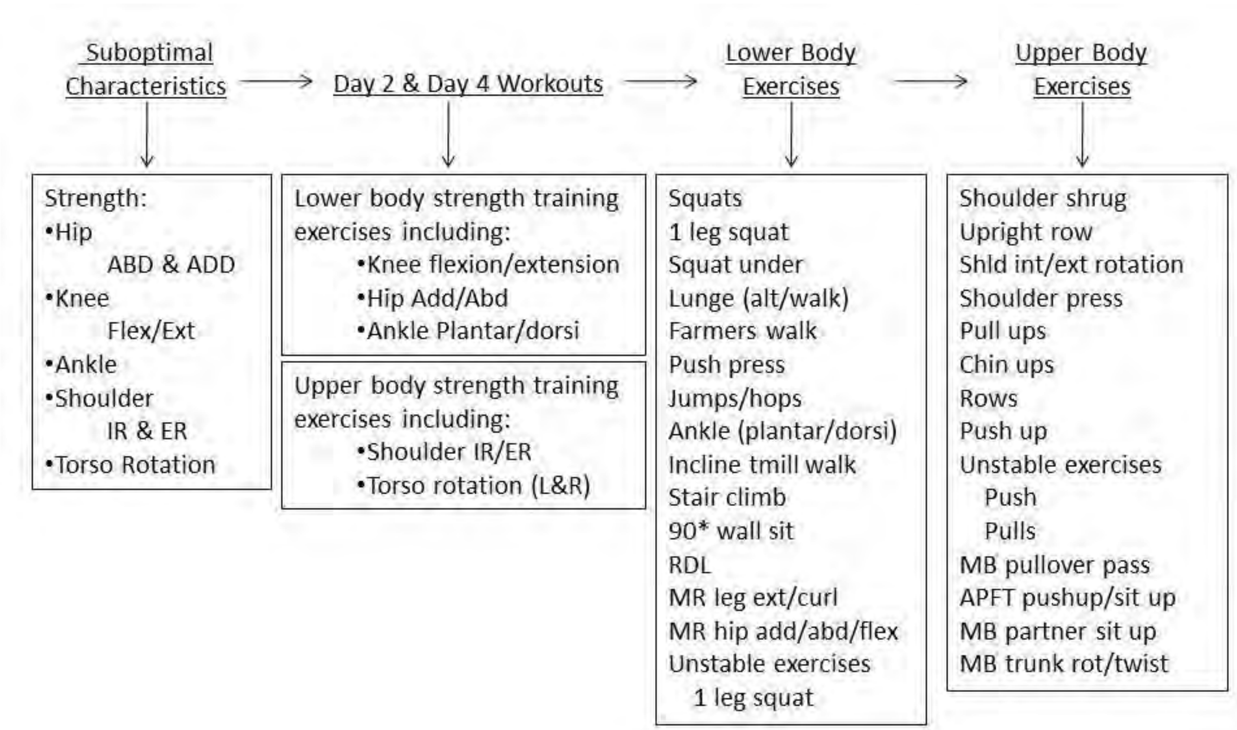
The Eagle Tactical Athlete Program (ETAP) is one of few evidence-based physical training program designed based on mitigate preventable musculoskeletal injuries and optimizing physical readiness. The study that has been outlined above demonstrates that our continued efforts to refine and improve ETAP for Soldiers with specific MOS and female Soldiers. A research-based approach to reduce the burden of musculoskeletal injuries sustained by the 101st Division Soldiers is shown to be effective and promising. Based on the current study on pilots with NP and LBP, pilots would likely benefit from an integrated ETAP focusing on routine pre-flight warm-up (10-15 minute duration) and a post-flight cool-down (13-15 minute duration). Exercises recommended in these pre- and post-flight sessions include neck, upper back, middle-lower back, hip stretching, and postural education through proper movement.

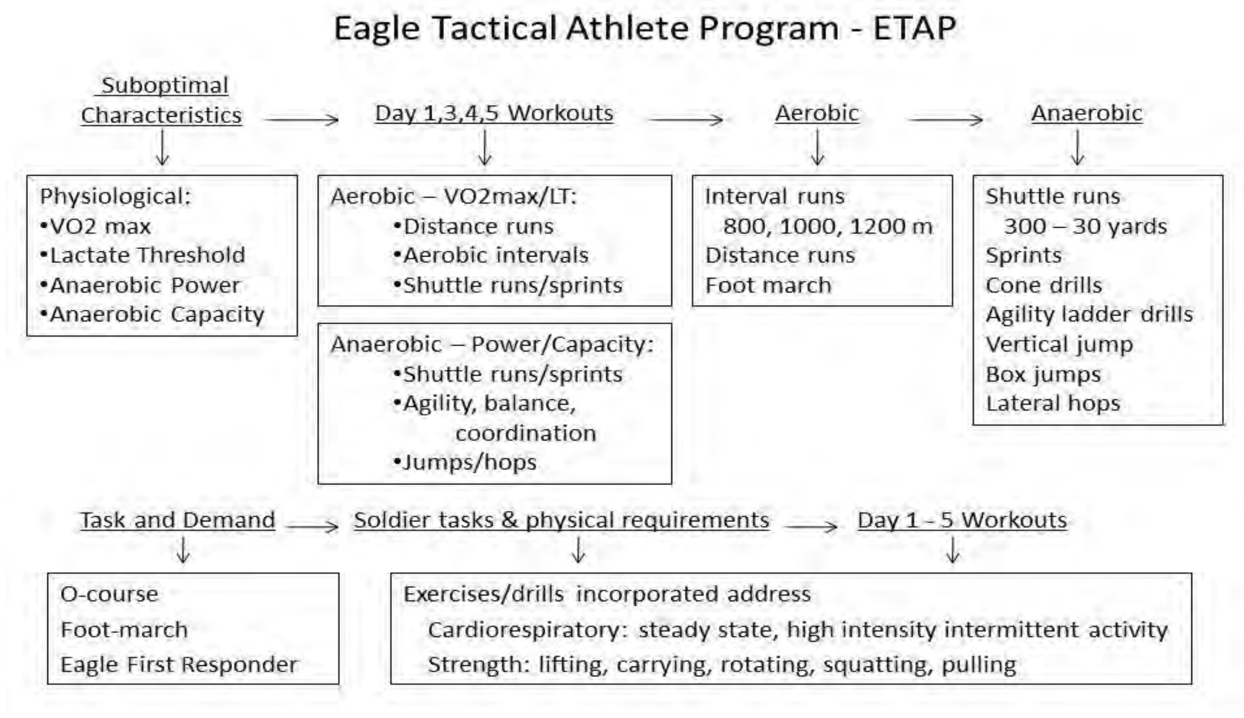
IV. Phase 3 Research Activities

Aim 1: Eagle Tactical Athlete Program

To evaluate the efficacy of ETAP to modify biomechanical, musculoskeletal, and physiological characteristics

ETAP was based on task and demand analyses, 101st-specific laboratory data, and previously identified predictors of injury. Laboratory data included 21 months of testing to identify suboptimal biomechanical, musculoskeletal, and physiological characteristics. ETAP followed a sports medicine periodized training model and included specific modalities designed to improve athleticism and mitigate musculoskeletal injuries. ETAP designed to require minimal equipment and flexible to various deployment environments.





ETAP is a cyclic program which allows for modifications to the individual training cycles according to unit schedules and missions. When implemented, each cycle is separated by one to two weeks of tapered activity to ensure proper recovery and to reduce the risk of overtraining. Each cycle is designed to build upon the previous cycle and varies in intensity and duration. ETAP is designed for implementation with little to no equipment and can be easily executed in garrison or while deployed. Overall volume, intensity, rest, and distance varies across the phases: phase I focuses on general adaptation and introduction to the exercises; phase II focuses on gradual increase in volume; phase III focuses on gradual increase in intensity with less volume, and phase IV focuses on taper prior to the post-test, deployment, or cycle reset. The program consisted of five main workout sessions per week over eight weeks, each with a specific fitness component focus (Table 1). Each workout session began with a dynamic warm-up and finished with a cool-down and static stretching. Each session was dedicated to one of the following training objectives: Day-1) speed, agility, and balance; Day-2) muscular strength; Day-3) interval training; Day-4) power development; and Day-5) endurance training. The total workout duration for each daily physical training session was consistent with the guidelines published in FM 21-20 and as instructed at Fort Campbell.

<u>The Day-1</u> workout session was designed to improve anaerobic power and capacity (which were identified as suboptimal during Predictors of Injury and Optimal Performance) and incorporated speed and agility exercises. Interval training with approximately a 1:3 or 1:2 work to rest ratio was incorporated for anaerobic system enhancement. Activities included shuttle runs, sprints, lateral movement drills, and agility drills. Shuttle runs and sprints used a funnel design, with the volume (total distance) progressing from high (274 m) to low (27 m) which dictated that the intensity progresses from low to high. Sprint training has been reported to induce neural adaptations, specifically increased nerve conduction velocity and motor-neuron excitability. Agility and lateral movement (line, cone, and ladder) drills progressed from simple patterns with shorter duration, distance, or volume to more complex patterns with longer duration, distance, or volume. Agility drills included line, cone, ladder drills, and advance shuttle and combined skills activities.

The Day-2 workout session was designed to improve muscular strength and muscular endurance, with the focus of increasing total body muscular strength. Strength training consisted primarily of resistance exercises that required no to a minimal amount of equipment and therefore could be executed anywhere. Equipment employed included the following: Interceptor Body Armor (IBA), body weight, sandbags, partner resistance, resistance tubing, and dumbbells. Exercise intensity, volume and rest were prescribed according to a recommendation by the American College of Sports Medicine and the volume was manipulated throughout the cycle by altering the duration the exercises were performed. The workout session incorporated full body strength training to ensure a well-balanced program and exercises were selected specifically to address muscle weaknesses and/or imbalances as identified during Predictors of Injury and Optimal Performance. Targeted muscles included hip adductor/abductor, hamstrings, the rotator cuff and trunk rotators.

The Day-3 workout session was designed to improve aerobic capacity through interval runs. The distance for the interval run ranged from 800-1200 m, with the interval run lasting between four to five minutes and performed at or near VO2max. Running faster than VO2max pace does not necessarily produce a greater aerobic benefit; therefore, the interval distance was carefully monitored and adjusted individually. Initially subjects were assigned to one of three interval distances based on APFT two-mile run times (≤ 15:00, 1200 m; 15:01 - 17:59, 1000 m; ≥ 18:00, 800 m). When a subject consistently finished the interval run in less than four minutes or greater than five minutes, then he/she was moved into a longer or shorter distance group, respectively. Prior to the workout, each Soldier was given an individualized goal time to complete the interval runs, based on the average time for his/her interval runs from the previous week. The work to rest ratio was designed to be close to 1:1, but varied by individual due to group size and individual finishing times. Early in the eight-week cycle, the rest time was slightly higher than the work time. As the cycle progressed, the rest time decreased slightly (with a minimum of 4:30 minutes). Also, the cycle began with two to three intervals with five minutes of rest/recovery and gradually progressed to four to five intervals with 4.5 minutes of rest/recovery. Static and dynamic balance drills also were performed at the completion of this workout. Several variation of one leg balance drills with eyes open and eyes closed were also performed.

The Day-4 workout session was designed to improve muscular strength and explosive power. This session built on the main workout session from Day-2. As with Day-2, the volume was manipulated throughout the cycle by altering the time that the exercises were performed. During the first four weeks of the cycle, circuit training which incorporated full body exercises along with upper and lower body plyometric exercises was performed. During weeks five and seven, the IBA was worn during the circuit, with no IBA during weeks six and eight to allow for rest/recovery. Proper landing technique was taught and landing drills executed to decrease ground reaction forces, which were identified in the companion paper as suboptimal. Intensity and volume of plyometric exercises were carefully monitored and introduced according to safety recommendations. Lower body plyometric exercises have been shown to reduce GRF due to a strength increase in the hamstring muscles accompanied by an improvement in the flexion/extension ratio. Teaching and utilizing proper landing techniques also reduces the impact forces, therefore decreasing the risk of injury. Training volume for lower body plyometric exercise was limited to 40-60 landings (4-6 exercises) per session and the jump intensity was limited to vertical jumps, tuck jumps, lateral and front-to-back line and cone hops/jumps, jumping rope, five dot drill and small box drills and landings. Upper body plyometric activities included APFT speed pushups, clapping pushups, and a variety of medicine ball exercises.

The Day-5 workout session was designed to improve aerobic endurance. Distance runs and foot marches were performed on alternate weeks. The goal was to increase aerobic capacity (VO2max) and foot march efficiency and therefore progressed from shorter to longer distances. For the foot march, the minimum pace was set at three miles per hour (20 min/mile) as per Fort Campbell standards. The initial distance was three miles and was increased by a half mile each march. Additionally, the load carried was gradually increased as follows: no load, IBA/Advance Combat Helmet (ACH), IBA/ACH with a 6.8 kg rucksack, and IBA/ACH with a 11.4 kg rucksack. Distance runs began with two to three miles at a steady pace and gradually progressed up to six miles.

Subjects

A sample of 60 male and female Soldiers from the 101st Airborne Division (Air Assault) were recruited from a single Brigade through posted advertisements and information sessions arranged by the investigators. All subjects were cleared for active duty without any injury profile prescribed throughout the study period or within the three months prior to enrollment. Subjects were matched on age, gender, and two-mile run time from their last APFT and then one member of each pair was randomly assigned to either an experimental group- ETAP (N: 30, Age: 24.6 ± 5.2 years, Height: 168.5 ± 24.5 cm, Mass: 68.3 ± 3.3 kg) or control group- current PT (N: 30, Age: 25.1 ± 5.8 years, Height: 168.5 ± 25.5 cm, Mass: 69.1 ± 3.3 kg). Human subject protection for the current study was approved by the University of Pittsburgh, Dwight D. Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All tests were conducted at the Human Performance Research Center, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

Experimental Design

A pretest/posttest randomized controlled design was used for this study. All subjects reported to the Human Performance Research Center for pre- and post-intervention testing. The experimental group participated in ETAP under the direction of an ETAP Strength and Conditioning Specialist while the control group performed current physical training at Fort Campbell as governed by FM 21-20 for the eight-week study period under the direction of the groups Physical Training Leader. Subjects reported each morning, Monday through Friday, at the regularly scheduled physical training time, for eight weeks. The ETAP Strength and Conditioning Specialist and Physical Training Leader were solely responsible for instructing physical training and were not involved with the data collection procedures.

Results

The 8-week trial was comprised of 35 training sessions and accounted for five days of no scheduled activities according to the Fort Campbell operating schedule. The average attendance for the experimental group was 89% (31 sessions) with a range of 54-100%. A minimum attendance of 80% of the training sessions was achieved by 80% of the subjects in the experimental group. The average attendance for the control group was 94% (33 sessions) with a range of 71-100%. A minimum attendance of 80% of the training session was achieved by 96% of the subjects in the control group.

Compared to the control group, the experimental group demonstrated improved active knee extension ($p < 0.001$), ankle dorsiflexion ($p = 0.018$), lumbar/hamstring flexibility ($p < 0.001$), and torso rotation flexibility ($p < 0.001$). No significant group differences were demonstrated in ankle plantar flexion ($p > 0.05$). Compared to the control group, the experimental group demonstrated significant improvements in knee extension strength ($p < 0.001$) and torso rotation strength ($p = 0.036$). No significant group differences were demonstrated in knee flexion or shoulder strength ($p > 0.05$). No significant group differences were demonstrated in eyes open or eyes closed balance ($p > 0.05$).

No significant group differences were demonstrated for percent body fat ($p > 0.05$). Compared to the control group, the experimental group demonstrated significant improvements in anaerobic power ($p = 0.019$). Compared to the control group, the experimental group demonstrated significant improvements in the sit-up ($p = 0.022$) and two mile timed run ($p = 0.039$) portions of the APFT, vertical jump ($p = 0.042$), agility ($p = 0.019$), and 300 yard shuttle run ($p = 0.005$).

No significant differences were demonstrated for the biomechanical variables ($p > 0.05$).

Conclusions

On average a 7-27% improvement was demonstrated in the experimental group performing ETAP.

V. Phase 4 Research Activities

Instructor Certification School (ICS)

A total of 1960 Soldiers participated in the ETAP Instructor Certification School (ICS). Essential to ICS is the “train the trainer” concept. Part of each graduate’s responsibility was to teach ETAP to other leaders/Soldiers who were unable to attend ICS. Two Soldiers per platoon were recommended and participated. To recruit an equal number of Soldiers from each Brigade and accelerate Division-wide implementation, six to eight ICS sessions (weeks) were scheduled for each Brigade, with the unit assignment based on the Brigade’s and Division’s training cycle.

The ETAP Instructor Certification School (ICS) is a four-day program designed to teach physical training leaders (NCOs) how to implement and effectively instruct ETAP at the unit level. The goals of ICS include: 1) experience and understand a comprehensive physical fitness program, 2) understand the components and underlying principles of ETAP in order to be able to adapt it to individual or unit situations, and 3) develop a working understanding of how to implement ETAP with little to no equipment to ensure that the program is deployable. Daily activities over the four day course allow for participants to achieve these goals through a multifaceted learning approach. The Soldiers were familiarized with the exercises and the program through participation in ETAP training sessions; interactive sessions including traditional lectures and presentations as well as open discussion to ensure proper understanding of the theory behind the program. Proper technique, progressions, and corrections for the exercises, and alternative exercises and/or training that can be employed while still accomplishing the same goals are covered during “hands on” practice sessions to implement and instruct ETAP.

A course outline for ICS is summarized in Table 9. Day-1 covered basic exercise physiology, warm-up/cool-down, stretching, anaerobic conditioning, and agility exercises. Day-2 covered nutrition and resistance exercises. Day-3 covered aerobic interval workouts, balance exercises, partner resistance exercises, and proper lifting techniques. Day-4 covered plyometric exercises, IBA workouts, medicine ball exercises, landing techniques, and PT program design. At the completion of ICS, students received the eight week ETAP workout cards along with the corresponding DVD. The DVD contains all of the lecture slides, a written description and videos of all exercises performed, exercise progression guidelines, perceived exertion and heart rate guidelines as well as information to develop alternative ETAP exercises given the deployment environment.

The validated eight-week ETAP program will be extended to account for the longer duration (deployment scheduled-dependent) with repeated cycles of increasing intensity. The monthly program will contain the same principles by which the eight-week model was developed, but will modify the progression of each training modality. The weekly training format will remain the same with individual days dedicated to different components of fitness, yet allowances will be built into the program to account for combat focus training.

Pilot of ICS Implementation

Classes initially consisted of NCOs from the Sustainment Brigade who were responsible for administering unit level PT. The NCOs learned the theory and implementation of an updated PT program (ETAP) and at the completion of the course were certified as Elite Tactical Athlete Program Training Leaders. The Elite Tactical Athlete Program Instructor Certification School curriculum covered training program design and implementation, exercise techniques and selection, basic exercise physiology, and nutrition. Each Elite Tactical Athlete Program Instructor Certification School class was scheduled for four days, with a maximum enrollment of 24 NCOs per class. Separate classes were scheduled for five weeks, totaling approximately 120 NCOs from the Sustainment Brigade. It was recommend that each platoon send two or three NCOs to the school together to better implement the program in their unit. Classes were held at the Human Performance Research Center at the Clarksville Base Gym from 0930 – 1500 each day. The

NCOs participated in the ETAP each morning and received both lecture and practical education. The NCOs were required to wear their Army Physical Training Uniform throughout the school.

A second, but equally important objective was to pilot the implementation of the newly learned ETAP into unit level PT. The aim of the piloting was to identify any potential logistical concerns which may need to be modified in order to ensure successful implementation to the Division. Unit level implementation was administered by the NCOs who recently complete the Elite Tactical Athlete Program Instructor Certification School. At the completion of the five weeks of the Elite Tactical Athlete Program Instructor Certification School, platoon NCOs returned to their units with all of the necessary information to instruct ETAP based on the concepts learned at the school. The certified NCOs received planning materials and exercise descriptions to assist in the delivery of the program. Quality control audits were conducted by the Human Performance Research Laboratory personnel to ensure proper delivery of this training program by the NCOs to their units, answer questions related to the implementation, and assess correct performance of the exercises by the Soldiers at the unit level.

Formal ICS Implementation

Formal enrollment into the Elite Tactical Athlete Program Instructor Certification School was phase-implemented based on individual Brigades. Enrollment in the Elite Tactical Athlete Program Instructor Certification School and Division implementation of ETAP was phased according to Brigade and deployment schedules and adjusted as necessary to account for deployment.

Upon completion of each weekly class, the corresponding NCOs implemented the learned ETAP into their respective units as part of the daily PT. ETAP was extended from the validated eight week format to a monthly periodized program. The monthly program contained the same principles by which the eight week model was developed, but modified the progression of each training modality to account for the longer duration (deployment schedule-dependent). The weekly training format remained the same with individual days dedicated to a single training principle, yet allowances were built into the program to account for combat focus training. The certified NCOs receive weekly planning materials and exercise descriptions to assist in the delivery of the program. Quality control audits were conducted by the Human Performance Research Laboratory personnel to ensure proper delivery of the ETAP by the NCOs to their respective units, answer questions related to the implementation, and assess correct performance of the exercises by the Soldiers at the unit level.

Validation of Unit Level Instructed ETAP

Background

The effectiveness of any physical training program is limited by structure of the program and the knowledge and skills of the instructor. The Eagle Tactical Athlete Program (ETAP) was developed for the Soldiers of the 101st Airborne Division (Air Assault) and previously validated to favorably modify human performance characteristics when implemented by the investigators. The purpose of the analysis was to validate the effectiveness of ETAP to modify human performance characteristics when instructed at the unit level by Soldiers who previously completed the ETAP Instructor Certification School (ICS) as one of the individual training courses offered by the Division.

Testing Overview

A total of 34 Soldiers (30 males and 4 females, Age: 27.1 ± 7.0 years, HT: 176.4 ± 8.4 cm, WT: 80.4 ± 13.4 kg) participated in the study. Pre and post testing was performed to assess changes in physiological (body composition, aerobic capacity, and anaerobic power/capacity), strength, flexibility, postural stability, and Army physical fitness test (APFT). All testing was conducted over two days (approximately one week apart), with each session lasting approximately two hours, at the University of Pittsburgh Human Performance Research Center (Fort Campbell, KY).

Eagle Tactical Athlete Program Description

The ETAP is a research-based, comprehensive injury prevention and human performance program developed for the 101st Airborne Division (Air Assault) and was designed to optimize the Soldiers' tactical capability and improve resiliency to unintentional musculoskeletal injuries. The physical training sessions (five training sessions per week) for ETAP consist of a dynamic warm-up followed by the main workout, with each session dedicated to one of the following training objectives: Day 1) speed, agility, and balance; Day 2) muscular strength; Day 3) interval training; Day 4) power development; and Day 5) endurance training. All training sessions conclude with static stretching and supplemental exercises. Overall volume, intensity, rest, and distance vary across the phases: phase I focuses on general adaptation and introduction to the exercises; phase II focuses on gradual increase in volume; phase III focuses on gradual increase in intensity with less volume, and phase IV focuses on taper prior to deployment or to reset of the periodized cycle. The ETAP program in the previous study was lead by experienced strength and conditioning coaches. The current study was led by unit-level instructors for 3-4 months.

Physiological Data Collection

Body composition was assessed with the Bod Pod® Body Composition System (Life Measurement Instruments, Concord, CA). Male subjects wore spandex shorts and a swim cap while female subjects wore spandex shorts, a sports bra, and swim cap. Once two consistent body volume measurements were obtained, percent body fat was calculated using predicted lung volume and the appropriate body densitometry equation. Additional variables obtained included body mass and percent of fat and fat-free mass. Body mass index (BMI) was also calculated for each subject.

A Wingate protocol using an electromagnetic cycle ergometer (RacerMate, Inc, Seattle, WA) was used to measure anaerobic power and capacity. Following a warm-up at a self-selected cadence at 125 Watts, the 50 second protocol was performed as follows: 15 seconds maintaining 100RPM at 125 Watts with minimal resistance; five seconds sprinting to generate maximum speed prior to initiation of normalized resistance; and 30 seconds attempting to sprint and maintain as much speed as possible against the normalized resistance. Standardized braking torques were utilized for males (9% body weight) and females (7.5%). Variables reported included anaerobic power and anaerobic capacity.
Maximal oxygen consumption (VO2max : ml/L) and lactate threshold were assessed during an incremental ramp protocol using a portable metabolic system (OxyCon Mobile, Viasys, Yorba Linda, CA) and a portable lactate analyzer (Arkray, Inc, Kyoto, Japan), respectively. Following a five minute warm-up, testing began. The test was performed in three minute stages, with the initial stage at 0% grade and each subsequent stage increased by 2.5% grade until exhaustion (cardiovascular or peripheral inhibition). Speed was set at 70% of each subject's two-mile run time during the Army Physical Fitness Test and remained constant throughout the test. Blood samples were obtained via a finger prick during the last minute of each stage and prior to an increase in incline in order to assess blood lactate levels. Heart rate (Polar USA, Lake Success, NY) and VO2 data were collected and monitored continuously throughout the test. The following variables were analyzed: relative VO2max , maximum heart rate, VO2 at lactate threshold, percent of VO2max at lactate threshold, heart rate at lactate threshold, and percent of maximum heart rate at lactate threshold.

Strength Data Collection

The Biodex Multi-Joint System 3 Pro was used to collect the following strength data: shoulder internal/external rotation, shoulder abduction/adduction, hip abduction/adduction, knee flexion/extension, ankle plantarflexion/dorsiflexion, and torso rotation. Subjects performed three practice trials at 50% maximum effort followed by three practice trials at 100% effort. Following a rest period of at least 60 seconds, five repetitions of reciprocal concentric isokinetic testing was performed at 60°/second for the shoulder, knee, and torso. Hip abduction/adduction was assessed isometrically in a sidelying, neutral hip position. Subjects performed three sets of 5 second isometric contractions, alternating between hip abduction and adduction. Ankle plantarflexion/dorsiflexion was assessed isometrically in a seated position with the knee and hip at 90°. Subjects performed three sets of 5 second isometric contractions, alternating between plantarflexion and dorsiflexion. A handheld dynamometer (Lafayette Instrument Company, Lafayette, IN) was used to assess ankle inversion and eversion strength with the subject long-sitting with the foot and ankle off the end of the table. Torque values from the Biodex testing and force values from the hand-held dynamometer were normalized to subjects body mass, and a percent of their body mass was used for statistical analyses.

Flexibility Data Collection

Passive range of motion of the shoulder, hip, and knee were performed using a standard goniometer or digital inclinometer. Hip flexion was assessed in the supine position with the knee flexed while hip extension and knee flexion were assessed in the prone position. Shoulder flexion, abduction, and internal and external rotation were assessed in the supine position. Shoulder extension was assessed in the prone position. Posterior shoulder tightness was also assessed passively in the supine position. Active range of motion was used to assess hamstring flexibility at the knee with the active knee extension test and to assess gastrocnemius-soleus flexibility at the ankle with active dorsiflexion with the knee straight. Active torso range of motion was performed while seated using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY).

Postural Stability Variables

A single force plate (Kistler 9286A, Amherst, NY) with a sampling frequency of 200 Hz was used to conduct balance testing. Three, 10 second trials of a single-leg standing balance test were performed with subjects barefooted and with their hands on their hips, under eyes opened and eyes closed conditions. Average center of pressure (COP) velocity in x and y direction and variations of ground reaction forces (GRF) in x, y, and z directions in addition to the cumulative GRF were used for statistical analyses.

For dynamic postural stability, a two-legged jump from a distance of 40% of subjects' height over a 12-inch hurdle onto a force place with a single-leg was performed. Subjects were instructed to stabilize as quickly as possible and remain still for 10 seconds with their hands on their hips. Three trials for each leg were conducted. Dynamic postural stability index (DPSI) is the composite score of the anterior-posterior (APSI), medial-lateral (MLSI), and vertical directions (VSI). Each index scores were used for statistical analyses.

Army Physical Fitness Test

The APFT was conducted by a non-commissioned officer in charge responsible for administering and scoring the individual components of the APFT. Subjects were allotted two minutes to perform maximum repetitions of situps, two minutes to perform maximum repetitions of push-ups, and timed two mile run according to APFT standards as outlined in FM 21-20. A 10-minute rest period was allowed between each testing component.

Statistical Analyses
Paired t-tests or Wilcoxon tests were used to evaluate significant differences pre- and post-intervention ($p < 0.05$).

Results

Overall exposure was 48.8 ± 17.7 days. Significant improvements were demonstrated in knee flexion, ankle inversion/eversion, and trunk flexion strength ($p < 0.05$). Shoulder extension, internal/external rotation, and posterior scapular flexibility as well as hip extension flexibility were significantly increased ($p < 0.05$). For static postural stability testing, single-leg eyes-closed COPx and GRFx,y,z,cu were significantly lowered. A reduction in MLSI and DPSI was only found in the left limb. Mean anaerobic power was significantly increased. Overall APFT was also increased significantly.

Conclusions

The results suggested that Soldiers who perform ETAP, when instructed by those who completed ICS training, demonstrated moderate improvements in various human performance variables. These improvements occurred despite the varied exposure rate due to training requirements and inability to perform physical training. Effective implementation ETAP to improve or maintain physical performance must consider training/continued training of the instructors (ICS), adjustments to physical training program based on tactical requirement priorities, and ability to complete while deployed.

Strength

	N	Mean	SD	N	Mean	SD	P value: paired ttest	P value: Wilcoxon signed rank test
SHLD IR R	34	51.32	12.59	34	52.19	13.16	0.478	0.554
SHLD IR L	34	46.61	11.86	34	46.13	11.58	0.735	0.840
SHLD ER R	34	37.86	9.31	34	37.18	8.48	0.444	0.447
SHLD ER L	34	34.03	6.48	34	33.84	6.47	0.773	0.906
SHLD IR/ER Ratio R	34	0.76	0.18	34	0.73	0.15	0.137	0.117
SHLD IR/ER Ratio L	34	0.75	0.15	34	0.76	0.17	0.803	0.698
KNEE FLEX R	34	104.97	18.46	34	114.85	21.91	0.001	0.002
KNEE FLEX L	34	102.14	18.16	34	111.77	21.39	0.001	0.001
KNEE EXT R	34	217.67	40.40	34	221.21	35.38	0.532	0.589
KNEE EXT L	34	212.00	29.28	34	214.86	32.53	0.482	0.510
KNEE FLEX/EXT Ratio R	34	0.49	0.09	34	0.52	0.08	0.061	0.039
KNEE FLEX/EXT Ratio L	34	0.48	0.06	34	0.52	0.08	0.001	0.001
HIP ABD R	34	161.31	32.33	34	153.42	36.12	0.146	0.256
HIP ABD L	34	162.13	34.82	34	156.21	30.59	0.277	0.388
ANKLE INV R	34	26.17	6.11	34	35.49	6.29	0.001	0.001
ANKLE INV L	34	26.71	5.46	34	32.12	5.85	0.001	0.001
ANKLE EVE R	34	23.58	4.83	34	27.49	5.66	0.001	0.001
ANKLE EVE L	34	24.73	5.80	34	28.25	5.10	0.001	0.001
ANKLE INV/EVE Ratio R	34	1.13	0.24	34	1.32	0.25	0.001	0.001
ANKLE INV/EVE Ratio L	34	1.11	0.19	34	1.16	0.22	0.149	0.101
TRUNK ROT R	34	145.84	34.29	34	140.79	34.02	0.357	0.532
TRUNK ROT L	34	145.29	33.14	34	141.57	35.21	0.427	0.566
TRUNK ROT R/L Ratio	34	1.00	0.12	34	1.01	0.10	0.791	0.933
TRUNK FLEX	34	188.38	60.08	34	206.57	51.71	0.093	0.018
TRUNK EXT	34	328.35	101.16	34	332.43	89.45	0.806	0.813
TRUNK FLEX/EXT Ratio	34	1.85	0.59	34	1.69	0.36	0.148	0.084

Flexibility

	N	Mean	SD	N	Mean	SD	P value: paired ttest	P value: Wilcoxon signed rank test
SHLD EXT R	34	55.73	20.90	34	62.57	11.42	0.076	0.011
SHLD EXT L	34	60.18	20.58	34	68.68	11.38	0.011	0.001
SHLD ER R	34	101.31	19.85	34	116.13	11.04	0.001	0.001
SHLD ER L	34	96.70	18.36	34	113.64	10.36	0.001	0.001
SHLD IR R	34	65.98	9.37	34	58.91	9.07	0.001	0.001
SHLD IR L	34	70.76	9.88	34	69.74	10.27	0.500	0.627
SHLD PST R	34	104.02	7.08	34	108.36	6.53	0.014	0.010
SHLD PST L	34	104.37	7.04	34	111.13	5.84	0.001	0.001
KNEE EXT R	34	15.87	9.89	34	15.86	9.33	0.993	0.877
KNEE EXT L	34	14.43	10.60	34	13.72	9.56	0.472	0.332
HIP EXT R	34	30.63	8.32	34	33.78	6.40	0.012	0.002
HIP EXT L	34	31.86	8.14	34	32.94	5.97	0.338	0.315
ANKLE DF R	34	17.11	7.51	34	16.35	8.47	0.532	0.606
ANKLE DF L	34	16.23	7.30	34	16.94	7.76	0.532	0.656
TRUNK ROT R	34	73.99	10.14	34	73.61	9.37	0.841	0.328
TRUNK ROT L	34	68.74	8.72	34	70.58	10.00	0.296	0.151
ANKLE PF R	34	54.12	7.61	34	52.89	8.69	0.358	0.167
ANKLE PF L	34	55.00	12.32	34	50.75	8.33	0.054	0.043

Balance

	N	Mean	SD	N	Mean	SD	P value: paired ttest	P value: Wilcoxon signed rank test
EO GRFx R	34	2.60	0.68	34	2.46	0.71	0.058*	0.030
EO GRFx L	34	2.69	0.82	34	2.58	0.77	0.388	0.301
EO GRFy R	34	3.32	1.21	33	3.13	1.05	0.225	0.140
EO GRFy L	34	3.14	0.99	33	3.32	1.33	0.557	0.846
EO GRFz R	34	4.17	1.62	34	4.31	1.87	0.672	0.879
EO GRFz L	34	4.39	1.82	34	4.40	1.98	0.988	0.761
EO GRFcu R	34	5.99	1.96	34	5.92	2.02	0.821	0.352
EO GRFcu L	34	6.09	2.08	34	6.10	2.41	0.980	0.648
EC GRFx R	34	6.20	2.16	34	4.99	1.74	0.001	0.000
EC GRFx L	34	5.90	2.56	34	4.99	2.11	0.006	0.006
EC GRFy R	34	9.87	4.15	33	8.15	3.40	0.019	0.003
EC GRFy L	34	9.16	4.52	33	8.57	5.08	0.308	0.214
EC GRFz R	34	15.43	14.53	34	9.64	4.70	0.028	0.004
EC GRFz L	34	13.75	20.16	34	10.50	6.36	0.322	0.379
EC GRFcu R	34	19.85	14.57	34	13.65	5.68	0.017	0.003
EC GRFcu L	34	18.14	20.28	34	14.50	8.12	0.227	0.256
Dynamic MLSI R	28	0.03	0.01	30	0.03	0.01	0.770	0.726
Dynamic MLSI L	30	0.03	0.01	29	0.03	0.01	0.039	0.022
Dynamic APSI R	28	0.14	0.01	30	0.14	0.01	0.535	0.603
Dynamic APSI L	30	0.14	0.01	29	0.14	0.01	0.254	0.339
Dynamic VSI R	28	0.36	0.05	30	0.34	0.04	0.320	0.264
Dynamic VSI L	30	0.36	0.04	29	0.33	0.04	0.056	0.052
Dynamic DPSI R	28	0.39	0.04	30	0.37	0.04	0.307	0.277
Dynamic DPSI L	30	0.39	0.04	29	0.36	0.03	0.043	0.032

Physiology

	N	Mean	SD	N	Mean	SD	P value: paired ttest	P value: Wilcoxon signed rank test
% Body Fat	34	22.72	6.60	34	22.07	6.79	0.084	0.076
BMI	34	25.72	3.14	34	25.57	3.51	0.479	0.944
HRLT	31	168.65	12.55	31	170.61	12.23	0.460	0.426
HRMax	33	192.97	9.15	34	192.41	8.97	0.506	0.429
HR_Per_LT	31	87.50	5.11	31	88.49	4.28	0.444	0.495
MAnP	34	7.59	1.09	34	7.81	1.02	0.035	0.031
PAnP	34	13.54	2.46	34	13.90	2.08	0.206	0.256
VO2LT	31	34.32	3.69	31	34.81	4.29	0.963	0.928
VO2Max	33	43.90	5.78	34	42.59	4.29	0.048*	0.059
VO2_Per_LT	31	80.06	6.75	31	82.18	4.77	0.315	0.265

APFT

	N	Mean	SD	N	Mean	SD	P value: paired ttest	P value: Wilcoxon signed rank test
PUSH-UP	31	57.26	14.44	31	58.32	11.11	0.522	0.470
SIT-UP	31	63.39	11.36	31	66.23	9.34	0.080	0.082
2-MILE RUN TIME	31	15.69	1.15	31	15.58	1.18	0.279	0.145
APFT SCORE	31	239.81	25.29	31	246.45	25.11	0.037	0.045

Validation of ETAP Injury Mitigation

Background

The Eagle Tactical Athlete Program (ETAP) was scientifically developed specifically for the US Army's 101st Airborne Division (Air Assault) to counter the significant number of sustained unintentional musculoskeletal injuries. ETAP was previously demonstrated to improve human performance characteristics, but the capability of ETAP to reduce injuries had not been studied. Therefore, the purpose of the aim was to determine if ETAP would reduce unintentional musculoskeletal injuries in garrison in a group of 101st Airborne Division (Air Assault) Soldiers.

Methods

Two Combat Brigades within the 101st Airborne Division (Air Assault) were enrolled in the study. Combat Brigades were like infantry units and selected due to similar deployment schedules and to the same environment. Prior to the Brigade implementation, non-commissioned officers attended a 4-day school to learn how to conduct ETAP for their respective units and they were in charge of morning PT for the experimental group. The experimental group performed ETAP for five months between prior to deployment. A total of 1641 Soldiers were enrolled (N = 1106 experimental group, N = 540 control group) to evaluate changes in injury data.

Injuries were tracked for five months prior to and after ETAP participation during a pre-deployment workup phase. ICD-9CM codes were used to categorize preventable musculoskeletal injuries (total, regional distribution, acute or overuse). A McNemar analysis was conducted to evaluate the effect of ETAP on the overall injury rate within each group.

Results

There was a significant reduction in overall injury rates (pre-ETAP: 209/1106 (18.9%), post-ETAP: 177/1106 (16.0%), $p = 0.045$) in the experimental group while no differences in the control group were found. A reduction in injury rates were also observed in overuse injuries and specific injuries to the lower extremity, knee, and lumbopelvic region in the experimental group.

Conclusions

The Eagle Tactical Athlete Program was scientifically designed to optimize performance and reduce injuries. The current analysis demonstrated that ETAP reduces preventable musculoskeletal injuries in garrison. The capability of ETAP to reduce injuries confirms the vital role of a scientifically designed training program on force readiness and health.

Table:

	Experimental Group			Control Group		
	Pre-ETAP	Post-ETAP	p	Pre-ETAP	Post-ETAP	P
All Injuries	209 (18.9%)	177 (16.0%)	0.045	105 (19.4%)	96 (17.8%)	0.460
Upper Extremity Injuries	5 (0.5%)	7 (0.6%)	0.774	5 (0.9%)	4 (0.7%)	1.000
Lower Extremity Injuries	120 (10.9%)	99 (9.0%)	0.117	60 (11.1%)	48 (8.9%)	0.207
Spine Injuries	89 (8.1%)	82 (7.4%)	0.569	47 (8.7%)	46 (8.5%)	1.000
Shoulder Injuries	5 (0.5%)	4 (0.4%)	1.000	5 (0.9%)	2 (0.4%)	0.453
Elbow Injuries	1 (0.1%)	3 (0.3%)	0.625	0 (0.0%)	1 (0.2%)	N/A
Hip Injuries	13 (1.2%)	9 (0.8%)	0.481	5 (0.9%)	2 (0.4%)	0.453
Knee Injuries	59 (5.3%)	46 (4.2%)	0.208	31 (5.7%)	32 (5.9%)	1.000
Lower Leg Injuries	9 (0.8%)	4 (0.4%)	0.180	3 (0.6%)	1 (0.2%)	1.000
Ankle Injuries	50 (4.5%)	42 (3.8%)	0.434	22 (4.1%)	14 (2.6%)	0.169
Cervical Spine	16 (1.5%)	13 (1.2%)	0.690	5 (0.9%)	5 (0.9%)	1.000
Thoracic Spine	3 (0.3%)	2 (0.2%)	1.000	2 (0.4%)	1 (0.2%)	1.000
Lumbar Spine	75 (6.8%)	69 (6.2%)	0.606	38 (7.0%)	41 (7.6%)	0.775
Acute Injuries	107 (9.7%)	90 (8.1%)	0.213	55 (10.2%)	45 (8.3%)	0.302
Overuse Injuries	59 (5.33%)	44 (3.98%)	0.086	26 (4.8%)	20 (3.7%)	0.451

Human Subjects Protections

Human subject protections compliance was maintained by review boards from the University of Pittsburgh and Dwight D. Eisenhower Army Medical Center, and higher level review performed by Clinical Investigation Regulatory Office and Office of Research Protections, Human Research Protection Office HRPO). All approvals were maintained throughout the project term of performance.

VI. Key Research Accomplishments

Physical Readiness

- Demonstrated improvements in musculoskeletal and physiological characteristics necessary for tactical readiness
- Demonstrated improvements in performance testing and the Army Physical Fitness Test
- ETAP successfully implemented by ICS Certified 101st Airborne Division (Air Assault) Non-Commissioned Officers at the unit level

Injury Mitigation

- Significant reduction in preventable musculoskeletal injury rates including overuse injuries and injuries to the lower extremity, knee, lumbopelvic regions

VII. Reportable Outcomes

Abstracts

1. McFate DA, Nagai T, Abt JP, Sell TC, Smalley BW, Wirt MD, Lephart SM. Neck Strength, Flexibility, Posture, and Proprioception Differences between Healthy Male and Female Soldiers in the US 101st Airborne Division (Air Assault). National Athletic Trainers' Association Annual Meeting; June 24-27, 2013; Las Vegas, NV.
2. Nagai T, Abt JP, Sell TC, Keenan KA, Smalley BW, Wirt MD, Lephart SM. Comparison of Trunk and Hip Strength and Flexibility between Pilots with and without a Self-Reported History of Low Back Pain. National Athletic Trainers Association Annual Meeting; June 24-27, 2013; Las Vegas, NV.
3. Sell TC, Abt JP, Nagai T, Deluzio J, Lovalekar M, Wirt, M, Lephart S. The Eagle Tactical Athlete Program Reduces Musculoskeletal Injuries in the 101st Airborne Division (Air Assault). 2013 American College of Sports Medicine. May 28- June 1, 2013; Indianapolis, IN.
4. Nagai T, Abt JP, Sell TC, Clark NC, Smalley BW, Wirt MD, Lephart SM. Neck Strength, Flexibility, Posture, and Proprioception in U.S. Army Pilots with and without a History of Neck Pain. Aerospace Medical Association Annual Meeting; May 12-16, 2013; Chicago, IL.
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6. Lovalekar M, Abt J, Sell T, Nagai T, Deluzio J, Wirt M, Lephart S. Measuring self-reported recall of unintentional musculoskeletal injuries in an Army Airborne Division. 140th Annual Meeting and Exposition of the American Public Health Association; October 27-31, 2012; San Francisco, CA.
7. Crawford K, Darnell M, Stapel H, Lovalekar MT, Abt JP, Sell TC, McCord LJ, Wirt MD, Nagai T, Deluzio JB, Lephart SM, FACSM. Dietary Supplement Habits of Soldiers of 101st Airborne Division Air Assault. 2012 American College of Sports Medicine. May 29- June 2, 2012; San Francisco, CA.
8. Clark NC, Keenan KA, Abt JP, Sell TC, Nagai T, Deluzio JB, Lovalekar MT, McCord LJ, Wirt MD, Lephart SM. Clinically Significant Side-to-Side Lower Extremity Strength Asymmetries in US Army 101st Airborne Soldiers. 59th Annual Meeting of the American College of Sports Medicine; May 29 - June 2, 2012; San Francisco, CA.
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11. Crawford K, Darnell ME, Abt JP, Sell TC, Lovalekar MT, House AJ, Smalley BW, Lephart SM. Dietary Habits of Soldiers of 101st Airborne Division Air Assault. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO. May 31-June 4.
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13. Keenan KA, Sell TC, Abt JP, Crawford K, House AJ, Smalley BW, Abt JP, Cardin S, Lephart SM. Physiological Differences Between Male and Female Army Soldiers Matched on Age and Years of Service. 2011 American College of Sports Medicine. May 31-June 4; Denver, CO.
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20. Nagai T, Sell TC, House AJ, Deluzio JB, Abt JP, Lovalekar MT, Smalley BW, Lephart SM . Shoulder flexibility and strength predict dynamic pushup ratio in the 101 st airborne division soldiers. Presented at: 57th ACSM Annual Meeting and World Congress on Exercise Is Medicine; June 2, 2010; Baltimore, MD.
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22. Fleishman K, Crawford K, Abt J, Sell T, Lovalekar M, Nagai T, Deluzio J, Rowe R, McGrail M, Lephart S. Optimal body composition for performance of 101 st airborne (air assault) soldiers. Presented at: 57th ACSM Annual Meeting and World Congress on Exercise Is Medicine; June 2, 2010; Baltimore, MD
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24. Abt JP, Sell TC, Nagai T, House AJ, Rowe R, McGrail M, Lephart SM. Field and laboratory testing variance and application to daily physical training. 2009 NATA Annual Meeting; June 17-20, 2009; San Antonio TX
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Manuscripts

Accepted

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3. Sell TC, Abt JP, Lovalekar M, Crawford K, Nagai T, Deluzio JB, Smalley BW, McGrail MA, Rowe RS, Lephart SM. Warrior Model for Injury Prevention and Human Performance- Eagle Tactical Athlete Program (ETAP) Part 1. Journal Special Operations Medicine. 2010: 10(4), 2-21
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In Preparation

1. Comparison of Trunk and Hip Strength and Flexibility between Pilots with and without a Self-Reported History of Low Back Pain. Aviat Space Environ Med
2. Warrior Model for Injury Prevention and Human Performance- Eagle Tactical Athlete Program (ETAP) Part 3. Military Medicine
3. Neck Strength, Flexibility, Posture, and Proprioception Differences between the Pilots with and without a History of Neck Pain. Aviat Space Environ Med
4. Gender differences in musculoskeletal, physiological, and balance characteristics. Military Medicine.
5. Dietary Intake of Army Soldiers in Occupation Specialties Requiring Heavy Physical Demands. Accreditation Council for Education in Nutrition and Dietetics
6. Field and laboratory testing variance and application to daily physical training. Medicine and Science in Sport and Exercise.
7. Comparison of Physical and Physiological Characteristics based on Service Experience and Age in US Army Soldiers. Military Medicine

Grant Submissions

- USASOC Injury Prevention/Human Performance Musculoskeletal Screening Initiative
- Naval Special Warfare Tactical Athlete Program Human Performance and Injury Prevention Research Initiative
- AFSOC Injury Prevention and Human Performance Research Initiative
- MARSOC Injury Prevention and Human Performance Research Initiative

VIII. Conclusions

ETAP was scientifically and specifically developed to address the burden of musculoskeletal injuries sustained by the Soldiers of the 101st Airborne Division (Air Assault) and optimize physical readiness. Over 3000 Soldiers were studied during tactical preparation exercises, at the University of Pittsburgh Warrior Human Performance Research Laboratory, and garrison and deployment environments. Upon completion of the ETAP Instructor Certification School 1900 Soldiers were certified to implement ETAP in Division PT.

- ETAP resulted in physical performance improvements with minimal equipment and exposure
- ETAP resulted in a reduction of overall and regional preventable musculoskeletal injuries
- Capability of ETAP to reduce injuries and optimize performance confirms vital role of a scientifically designed and implemented training program on force readiness and health of Soldiers of the 101st Airborne Division (Air Assault)

IX. References

Not applicable

X.Appendices

Attached

Approval and Agreement with the Proposed Research Project:
Injury Prevention and Performance Enhancement in 101st Army Airborne Soldiers
101st Airborne Division, Ft Campbell, Kentucky and the
University of Pittsburgh Medical Center

FROM: LTC Rusty Rowe
Division Surgeon, 101st ABN DIV (AA)
Ft. Campbell, Kentucky

TO: Dr. Sylvain Cardin, PhD
Senior Medical Science & Technology Consultant
Program Administrator
Telemedicine & Advanced Technology Research Center
U.S. Army Medical Research and Material Command

We have read and understand the research proposal titled 'Injury Prevention and Performance Enhancement in 101st Army Airborne Soldiers', with Dr. Scott Lephart, PhD, ATC as the Principal Investigator.

We understand this research project is a collaborative effort between the University of Pittsburgh Medical Center (UPMC) and the Army 101st Airborne Division (Air Assault) at Ft. Campbell, Kentucky.

We approve of and agree to the research that is proposed, the methods by which the research objectives are to be met, and the manner that the research will be conducted, subject to compliance with Army Regulation 40-38, Clinical Investigation Program, 1 September 1989, and any other Department of Defense requirements for clinical investigations that may apply to this research study.

Furthermore, we understand that the research will be conducted and carried out on the premises of Ft. Campbell, as indicated in this proposal. Any anticipated renovation of facilities is subject to the Department of Army fiscal and budgetary constraints.

We agree that Dr. Scott Lephart and others as listed in the proposal, will be allowed access to Soldiers of the 101st Airborne Division (Air Assault) for the purpose of requesting volunteers to participate in this research as described in the proposal.

The parties understand and agree that this study may be terminated upon a determination by the Commanding General, 101st Airborne Division (Air Assault) that operational and mission requirements can no longer support the research project.

Date: 8 June 2006

Major General Thomas R. Turner II
Commanding General
101st Airborne Division (Air Assault) and Fort Campbell

Date: 7 Jun 06

LTC Rusty Rowe
Division Surgeon, 101st ABN DIV (AA)
Ft. Campbell, Kentucky

Approval and Agreement with the Proposed Research Project:
Injury Prevention and Performance Enhancement in 101st Army Airborne Soldiers
101st Airborne Division, Ft Campbell, Kentucky and the
University of Pittsburgh Medical Center

FROM: LTC Rusty Rowe
Division Surgeon, 101st ABN DIV (AA)
Ft. Campbell, Kentucky

TO: All Concerned

We have read and understand the research proposal titled 'Injury Prevention and Performance Enhancement in 101st Army Airborne Soldiers', with Dr. Scott Lephart, PhD, ATC as the Principal Investigator.

We understand this research project is an on going collaborative effort between the University of Pittsburgh Medical Center (UPMC) and the Army 101st Airborne Division at Ft. Campbell, Kentucky.

We approve of and agree to the research that is proposed, the methods by which the research objectives are to be met, and the manner that the research will be conducted.

Furthermore, we understand that research will be conducted and carried out on the premises of Ft. Campbell as indicated in the proposal.

We agree that Dr. Scott Lephart and others as listed in the proposal, will have access to the soldiers of the 101st Airborne soldiers at Ft. Campbell Kentucky for the purpose of conducting this research as described in the proposal.

Date: 2/14/2007

Major General Jeffery J. Schloesser
Commanding General
101st Airborne Division (Air Assault) and Fort Campbell

Date: 2/14/2007

LTC Rusty Rowe
Division Surgeon, 101st ABN DIV (AA)
Ft. Campbell, Kentucky

DEPARTMENT OF THE ARMY
HEADQUARTERS, 101ST AIRBORNE DIVISION (AIR ASSAULT) AND FORT CAMPBELL
2700 INDIANA AVENUE
FORT CAMPBELL, KENTUCKY 42223-5656

REPLY TO
ATTENTION OF

March 3, 2008

Dr. Scott Lephart, PhD, ATC
Director, Neuromuscular Research Lab
Department of Sports Medicine and Nutrition
University of Pittsburgh
Pittsburgh, PA 15213

Dear Dr. Lephart,

The Soldiers of the 101st Airborne Division (Air Assault) and Fort Campbell, Kentucky are exceptionally fortunate to have the opportunity to participate in ground-breaking musculoskeletal research. The 101st Airborne Division (Air Assault) Injury Prevention and Performance Enhancement Research Initiative, administered by the University of Pittsburgh, is currently conducting initial phase two data collection on the musculoskeletal, physiological, and nutritional characteristics of Fort Campbell Soldiers. The effects of even this early data have been immediate and profound. Unit and medical leaders have an increased awareness of shortfalls in physical training programs and injury patterns. Soldiers completing the testing protocol receive immediate feedback from the researchers in the form of an individualized exercise prescription, nutritional guidance, and instruction regarding conditioning in a deployed environment. Advancing the research to phase three will foster the development of innovative physical training programs for Soldiers in garrison and field settings. These new approaches to physical training are projected to improve fitness and conditioning levels, leading to reduced injury rates and increased levels of Soldier readiness and combat effectiveness.

Soldiers across the Army deserve the health benefits afforded by state of the art medical research. The 101st Airborne Division (Air Assault) and Fort Campbell remain firmly committed to participation in the Injury Prevention and Performance Enhancement Research Initiative and the Army's investment in the early phases of the project. The program and protocols proposed by the University of Pittsburgh for phase three implementation will yield long term positive results that will enhance the medical readiness and combat effectiveness of all Soldiers. Air Assault!

Sincerely,

Jeffrey J. Schloesser
Major General, US Army
Commanding General

University of Pittsburgh

Department of Sports Medicine and Nutrition
School of Health and Rehabilitation Sciences
Neuromuscular Research Laboratory

Scott M. Lephart, PhD
Chairman
Principal Investigator

Neuromuscular Research Laboratory
3200 South Water Street
Pittsburgh, PA 15203
Phone: 412-432-3800
Fax: 412-432-3801
http://www.pitt.edu/~neurolab

Concur
12.26

15 Dec 08

MEMORANDUM THRU ELITE TATICAL ATHLETE TRAININING PROGRAM PRINICIAL INVESTIGATOR

FOR LTC MARK MCGRAIL AND MG JEFFREY SCHLOESSER to be shared upon approval with BG TOWNSEND, LTC KUNK, COL LEWIS, AND LTC SUTTON

SUBJECT: University of Pittsburgh Injury Prevention and Performance Optimization Research Study: Results of Pre-Deployment Clinical Trial and Proposal for Efficacy Trial, Piloting and Division Implementation of Elite Tactical Athlete Training Program and Elite Tactical Athlete Instructor Certification School

1. The attached report provides an Executive Summary and Technical Abstract of the validated Elite Tactical Athlete clinical trial performed (Aug 08 – Nov 08).

2. The attached report provides a proposal to conduct an efficacy trial to begin 12 Jan 09, pilot and then implement the Elite Tactical Athlete Instructor Certification School and Elite Tactical Athlete Training Program.

3. This report is for review and dissemination to those deemed appropriate.

4. The point of contact for this report is Scott M. Lephart, PhD, 412-432-3800 or lephartsm@upmc.edu

DEPARTMENT OF THE ARMY
HEADQUARTERS, U.S. ARMY MEDICAL DEPARTMENT ACTIVITY
FORT CAMPBELL, KENTUCKY 42223-5349

REPLY TO
ATTENTION OF:

8 April 2009

Office of the Commander

Dr. Scott Lephart, PhD, ATC
Director, Neuromuscular Research Lab
Department of Sports Medicine and Nutrition
University of Pittsburgh
Pittsburgh, PA 15213

Dear Dr. Lephart,

The innovative research projects being conducted by the University of Pittsburgh for the 101st Airborne Division (Air Assault) Injury Prevention and Performance Enhancement Research Initiative is highly beneficial to the continued health of our Soldiers. This program has proven crucial for enhancing the medical readiness and combat effectiveness of our troops.

The University of Pittsburgh's scientific systematic approach to physical and mental fitness reduces injuries and builds a more resilient Soldier. The study results and the expertise that the initiative offers have great potential when coupled with traumatic brain injury patients and Wounded Warriors. The applications could potentially greatly benefit those with traumatic brain injury and also the population of Wounded Warriors.

Blanchfield Army Community Hospital strives to provide the best medical care possible for our Soldiers, Families and Retirees. The continued research with The Injury Prevention and Performance Enhancement Initiative will greatly enhance the care we can offer our Soldiers. I offer my highest endorsement for the continuation of this research.

If you have any questions, I may be reached at (270) 798-8041.

Sincerely,

RW Thomas

RICHARD W. THOMAS, MD
Colonel, U.S. Army
Commanding

Commander, Warrior Transition Battalion, 101st Airborne/Air Assault Division, Ft. Campbell, KY

DEPARTMENT OF THE ARMY
HEADQUARTERS, WARRIOR TRANSITION BATTALION
U S. ARMY MEDICAL DEPARTMENT ACTIVITY
FORT CAMPBELL, KENTUCKY 42223-5349

REPLY TO
ATTENTION OF

MCXD-WTB

20 OCT 2009

MEMORANDUM FOR Fiscal Year 2009 (FY09) Department of Defense (DOD) Psychological Health and Traumatic Brain Injury Research Program (PH/TBI Research Program) Advanced Technology/Therapeutic Development Award Selection Committee

SUBJECT: Letter of Institutional Support for Exercise and Nutrition Intervention to Optimize Psychological Health for Soldiers of the Warrior Transition Battalion (WTB)

1. As the Warrior Transition Battalion Commander at Fort Campbell, KY, I will ensure our unconditionally support of Timothy C. Sell, PhD, PT as the Coordinating Primary Investigator and others involved in this research project.

2. Specifically we will ensure that acceptable access is granted to the nearly 800 Warriors in Transition that are members of the WTB. I believe that this project will have an important, beneficial and immediate impact on the overall physical and psychological health of the Soldiers in the Warrior Transition Battalion at Ft. Campbell, KY.

3. I am confident in the capabilities of all investigators involved in the study and that they will be successful in accomplishing the specific aims of the research project.

4. Point of contact for this memorandum is the undersigned at 270-956-0561.

CHRISTOPHER G. JARVIS
LTC, MC
Commanding

Lieutenant Colonel Christopher Gary Jarvis, MD, FAAFP, CAQSM – WTB, Ft. Campbell, KY (Co-PI)

DEPARTMENT OF THE ARMY
HEADQUARTERS, WARRIOR TRANSITION BATTALION
U.S. ARMY MEDICAL DEPARTMENT ACTIVITY
FORT CAMPBELL, KENTUCKY 42223-5349

REPLY TO ATTENTION OF

MCXD-WTB

20 OCT 2009

MEMORANDUM FOR Fiscal Year 2009 (FY09) Department of Defense (DOD) Psychological Health and Traumatic Brain Injury Research Program (PH/TBI Research Program) Advanced Technology/Therapeutic Development Award Selection Committee

SUBJECT: Letter of Collaboration for Exercise and Nutrition Intervention to Optimize Psychological Health for Soldiers of the Warrior Transition Unit (WTU)

1. In concert with Timothy C. Sell, PhD, PT as the Coordinating Primary Investigator and I as a Co-Primary Investigator on this proposal I unconditionally support this project with the following specific aims:

Specific Aim 1: Examine the effects of an exercise and nutritional intervention and education program on prevention of psychological health issues and co-morbid conditions

Specific Aim 2: Examine the effects of an exercise and nutritional intervention and education program on the treatment of psychological health issues and co-morbid conditions

Specific Aim 3: Examine the effects of an exercise and nutritional intervention and education program on recovery time and length of stay in the WTU

Specific Aim 4: Develop a model based on physical and physiological characteristics that predicts successful return to active duty and potential redeployment (return to readiness)

2. Specifically I believe that this project will have an important, beneficial and immediate impact on the overall physical health and psychological health of the Soldiers in the Warrior Transition Unit at Ft. Campbell, KY and that the research project will provide evidence of positive outcomes that can be carried over to other Warrior Transition Units and Military populations throughout the Department of Defense.

3. I am confident in the capabilities of all investigators of the study and that we will be successful in accomplishing each of the specific aims of the research project. All Primary Investigators have demonstrated that they have the resources necessary to complete this research proposal as demonstrated by prior successful research studies here at Fort Campbell, KY related to the Elite Tactical Athlete Program of the 101st Airborne (Air Assault) Division.

4. Point of contact for this memorandum is the undersigned at 270-956-0561.

CHRISTOPHER G. JARVIS
LTC, MC
Commanding

Lieutenant Colonel Brian W. Smalley, DO, MSPH – Division Surgeon, Ft. Campbell, KY (Co-I)

DEPARTMENT OF THE ARMY
HEADQUARTERS, 101st AIRBORNE DIVISION (AIR ASSAULT) AND FORT CAMPBELL
2700 INDIANA AVENUE
FORT CAMPBELL, KENTUCKY 42223-5656

REPLY TO
ATTENTION OF:

AFZB-SN 11 Oct 2009

MEMORANDUM FOR Dr. Timothy C. Sell, PhD, PT

SUBJECT: Letter of support for ancillary study

1. I would like to take this opportunity to give my support for the research grant titled "Exercise and Nutrition Intervention to Optimize Psychological Health for Soldiers of the Warrior Transition Unit. The number of wounded Warriors with mental health diagnoses has increased substantially since the beginning of the Global War on Terrorism. As the Division Surgeon for the 101st Airborne (Air Assault) Division I am concerned about the psychological health and, consequently, the Soldiers overall well being.

2. I have recently reviewed your proposal to study exercise and nutrition as an intervention to improve psychological health in Wounded Warriors. I support the University of Pittsburgh and your efforts to develop and test these two relatively unexplored interventions. I am confident in the design of the training program and its capability of improving Soldiers psychological health. I am excited and look forward to working with the research team and serving as a co-investigator.

3. POC for this memo is the Division Surgeon 270-798-6449 or brian.w.smalley@conus.army.mil.

//Original Signed//

BRIAN W. SMALLEY
LTC, MC, MFS
DIVISION SURGEON

DEPARTMENT OF THE ARMY
HEADQUARTERS, UNITED STATES ARMY
SPECIAL OPERATIONS COMMAND
2929 DESERT STORM DRIVE
FORT BRAGG, NORTH CAROLINA 28310-9110

REPLY TO
ATTENTION OF:

AOMD

September 14, 2009

Dr. Scott Lephart, PhD, ATC
Director, Neuromuscular Research Lab
Department of Sports Medicine and Nutrition
University of Pittsburgh
Pittsburgh, PA 15213

Dear Dr. Lephart,

The United States Special Operations Command (USASOC) has recently begun implementation of a human performance program aimed at optimizing the physical and mental conditioning of ARSOF personnel. This program, named THOR3 (Tactical Human Optimization, Rapid Rehabilitation and Reconditioning) will hire strength and conditioning specialists and physical therapists to execute the program at the unit level.

The three major goals of the THOR3 program are:

1. To increase human performance with peak functional performance and combat effectiveness.
2. Reduce SOF manpower lost to injury and disease through focused and individualized assessment and conditioning strategies.
3. To maximize return to duty times with optimized recovery and reconditioning.

What we feel is missing is the scientific arm to this program. We do not have a current study or program that can identify and prioritize what we need to rapidly improve or change in the current physical training program.

Your Injury Prevention and Performance Enhancement Research Initiative would be of tremendous benefit as our program is being developed and refined.

We will continue to aggressively pursue ways in which we can partner to achieve our goals.

Sincerely,

PETER J. BENSON, MD
COL, MC, SFS
Command Surgeon

DEPARTMENT OF THE ARMY
FORT CAMPBELL INSTALLATION
2700 INDIANA AVENUE
FORT CAMPBELL, KENTUCKY 42223-5656

REPLY TO
ATTENTION OF:

20 May 2010

Office of the Commander

Dr. Scott Lephart, PhD, ATC
Director, Neuromuscular Research Lab
Department of Sports Medicine and Nutrition
University of Pittsburgh
Pittsburgh, PA 15213

Dear Dr. Lephart:

The Soldiers of the 101st Airborne Division (Air Assault) and Fort Campbell, Kentucky are exceptionally fortunate to continue to have the opportunity to particiapate in ground-breaking musculoskeletol research with the University of Pittsburgh.

The 101st Airborne Division (Air Assault) Injury Prevention and Performance Enhancement Research Initiative, administered by the University of Pittsburgh, continues to positively impact the physical readiness of our Soldiers. Since the summer of 2009, over 1,000 Soldiers were trained to implement ETAP methodologies at the platoon level in both garrison and deployed environments. I strongly support the ongoing research initiatives for the soldiers at Fort Campbell and the continued development and refinement of the studies related to ETAP. Specifically, the planned studies to develop nutritional strategies for soldier weight control needs, exercise and nutritional support of the soldiers of the Warrior Transition Battalion (WTB), and injury prevention human performance research of those soldiers of the 5th Special Forces Group at Fort Campbell.

Soldiers across the Army deserve, now more than ever, the health benefits afforded by state of the art medical research. Proving the Army's investment in the early phases of this project was an insightful success and the 101st Airborne Division (Air Assault) and Fort Campbell remain firmly committed to participation in this Injury Prevention and Performance Enhancement Research Initiative. We have every confidence that the program and protocols proposed by the University of Pittsburgh for the completion of phase three implementation will yield long term positive results that will enhance the medical readiness and combat effectiveness of all Soldiers. Air Assault!

John F. Campbell
Major General, US Army
Commanding

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE SPECIAL OPERATIONS COMMAND

1 May 2012

From: HQ AFSOC/SGR

To: University of Pittsburgh IRB

Subject: University of Pittsburgh Research Study

1. I have read and understand the research proposal titled "AFSOC Injury Prevention and Human Performance Research Initiative" with Dr. Timothy Sell, as the Principal Investigator.

2. I understand this research project will be performed by investigators from the University of Pittsburgh, and I approve and agree with the research that is proposed, the methods by which the research objectives will be met, and the manner in which the research will be conducted. Furthermore, I understand the research will be conducted and carried out on the premises of Air Force Special Operations Command, Hurlburt Field, FL.

3. I agree that Dr. Sell and others as listed in the proposal will have access to the AFSOC Operators for the purpose of conducting this research as described in the proposal. Any questions please contact Mr. Drew Reinert at 850-884-3507.

SCOTT F. WALTER, Lt Col, USAF, BSC, PE
Chief, Modernization Division,

Relationship between the Army Physical Fitness Test and Laboratory-Based Physiological and Musculoskeletal Assessments

John P. Abt, Timothy C. Sell, Takashi Nagai, Jennifer B. Deluzio, Karen Keenan, Rusty Rowe, Mark A. McGrail, Sylvain Cardin, Scott M. Lephart, FACSM
University of Pittsburgh, Department of the Army

The Army Physical Fitness Test (APFT) is administered twice a year and is designed to evaluate cardiorespiratory fitness, strength, and endurance. The APFT is scored according to gender and age for the number of completed sit-ups and push-ups per two minutes and a two mile run. Despite the goal of the testing protocol, the APFT may not provide a complete picture of individual military readiness or potential for injury.
PURPOSE: To determine the relationship between the APFT and laboratory testing for physiological and musculoskeletal variables. **METHODS:** A total of 90 male Army 101st Airborne (Air Assault) soldiers participated (Age: 28.4 ± 7.1 years; Height: 1.77 ± 0.08 m; Mass: 83.1 ± 12.2 kg). Subjects performed the standard APFT and a battery of laboratory assessments consisting of VO2 max, anaerobic power and capacity, torso rotation strength, shoulder internal and external rotation strength, quadriceps and hamstring strength, and body composition. The laboratory testing battery was based on variables that would most contribute to optimizing overall military readiness and those most likely related to injury in the Army. Subjects were ranked according to performance for each APFT and laboratory test, with a separate cumulative ranking score calculated for the APFT and laboratory tests. A Spearman Rho correlation was calculated to determine the relationship between the cumulative ranking scores for the APFT and laboratory tests. Secondary Spearman Rho correlations were run between the APFT cumulative ranking score and the individual laboratory tests. **RESULTS:** A moderate relationship was identified between the cumulative APFT and laboratory testing ($\rho = 0.653$, $p < 0.001$). A moderate relationship was identified between the APFT and the VO2 max ($\rho = 0.709$, $p < 0.001$), anaerobic capacity ($\rho = 0.654$, $p < 0.001$), and body composition ($\rho = 0.632$, $p < 0.001$).
CONCLUSION: The cumulative ranking relationship between the APFT and laboratory testing was mostly related to the VO2 max, anaerobic capacity, and body composition test. The lack of relationship between the APFT and the other laboratory tests suggests that despite the potential to score high on the APFT, additional or modified training is necessary to optimize military readiness and prevent musculoskeletal injury.

Deployment-Related Changes in Physical and Physiological Characteristics

John P. Abt, Timothy C. Sell, Takashi Nagai, Jennifer B. Deluzio, Mita T. Lovalekar, Kim Crawford, Brian W. Smalley, Sylvain Cardin, Scott Lephart FACSM. University of Pittsburgh, Pittsburgh, PA, 101st Airborne Division (Air Assault), Fort Campbell, KY

Lack of standard or consistent physical training performed by Soldiers during deployment impacts physical readiness preparation. Constraints reported by Soldiers include physical demand and fatigue due to tactical requirements, lack of available time, environmental conditions, and limited or austere facilities.

PURPOSE: To assess deployment-related changes in physical and physiological characteristics.

METHODS: A total of 23 active duty Soldiers from the 101st Airborne Division (Air Assault) participated (Age: 26.0 ± 5.8 years; Height: 178.8 ± 6.4 cm; Mass: 80.3 ± 12.8 kg; Pre Test-Deployment: 139 ± 17 days; Deployment: 433 ± 15 days; Deployment-Post Test: 30 ± 20 days). Pre and post deployment testing consisted of assessments of body mass (kg) and body composition (%BF), isokinetic knee flexion/extension strength (%BW), and anaerobic power/capacity (W/kg). A paired t-test was used to evaluate deployment related changes in the dependent variables. Variability was calculated for each measure to determine individual subject response.

RESULTS: Body mass (Pre: 80.3 ± 12.8 kg, Post: 83.2 ± 13.6 kg, $p = 0.02$) and anaerobic capacity (Pre: 7.7 ± 0.8 W/kg, Post: 7.4 ± 1.0 W/kg, $p = 0.019$) were worse post deployment. Knee flexion strength improved post-deployment (Pre: 112.3 ± 23.2, Post: 127.5 ± 23.7, $p = 0.002$). No changes were noted for body composition, knee extension strength, or anaerobic power ($p > 0.05$). The individual subject response for body mass was 22.4% loss – 26.9% gain, body composition was 30% loss – 70.3% gain, knee extension strength was 18.3% loss – 58.7% gain, knee flexion strength was 23.5% loss – 59.1% gain, anaerobic power was 33.1% loss – 32.0% gain, and anaerobic capacity was 23.6% loss – 10% gain.

DISCUSSION: Self-reported constraints may be weighted for each Soldier and impact the ability to perform physical training independently given large post deployment response variance. At the minimum a maintenance program should be performed to prevent diminished physical readiness while deployed. Post deployment changes in physical and physiological characteristics and self-reported constraints were considerations for development of the Eagle Tactical Athlete Program for the 101st Airborne Division (Air Assault).

Supported by USAMRMC/TATRC #W81XWH-06-2-0070/ W81XWH-09-2-0095

Kinematic adaptations with interceptor body armor in Soldiers of the Army 101st

Abt JP*, Lephart SM*, Sell TC*, Nagai T*, Chu Yungchien*, Rowe R†, McGrail M†: Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA*; Department of the Army, 101st Airborne Division (Air Assault), Ft Campbell, KY†

Context: Interceptor body armor (IBA) is critical to the protection of military personnel. The additional weight of the IBA may increase the musculotendinous demands and susceptibility to injury if training requirements have not specifically addressed the extra loads. **Objective:** The purpose of this study was to compare kinematic and force changes with and without IBA during a drop landing task. It was hypothesized that wearing IBA would result in altered landing mechanics and forces. **Design:** A within-subject, repeated measures design was utilized. **Setting:** University sports medicine laboratory. **Patients or Other Participants:** Twenty five 101st Airborne Soldiers participated (Age: 28.2 ± 6.9 years; Height: 1.78 ± 0.07 m; Mass: 82.8 ± 11.6 kg). **Interventions:** A 3D motion analysis and force plate system was used to capture kinematic and force data while subjects performed a single-leg, 50 cm drop landing task. The task was performed under eyes open and eyes closed conditions and with and without IBA. The IBA weighed 13.6 kg and represented the minimum additional weight required to be carried by the Soldiers. **Main Outcome Measures:** The dependent variables were knee flexion and valgus angle at initial contact, maximum knee flexion, time to maximum knee flexion, peak ground reaction forces, time to peak ground reaction forces, and average and peak slope of the ground reaction forces. **Results:** For the eyes opened condition, maximum knee flexion increased (NIBA: 80.9 ± 16.5°; IBA: 91.0 ± 13.4°; $p < 0.001$), time to maximum knee flexion increased (NIBA: 242.3 ± 99.0 ms; IBA: 350.9 ± 217.2 ms; $p = 0.004$), peak ground reaction forces increased (NIBA: 352.2 ± 88.4 %BW; IBA: 378.6 ± 76.0 %BW; $p = 0.011$), time to peak ground reaction forces increased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$), and average slope of peak ground reaction forces decreased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$). For the eyes closed condition, maximum knee flexion increased (NIBA: 78.9 ± 15.0°; IBA: 85.5 ± 10.8°; $p = 0.001$), time to maximum knee flexion increased (NIBA: 242.0 ± 118.1 ms; IBA: 300.0 ± 80.9 ms; $p = 0.003$), and peak ground reaction forces increased (NIBA: 353.8 ± 80.3 %BW; IBA: 373.6 ± 66.2 %BW; $p = 0.039$). **Conclusions:** Wearing IBA during the drop landing tasks resulted in altered mechanics and ground reaction forces. Proper integration of IBA into training is necessary to ensure musculoskeletal adaptation to carrying the additional loads required of tactical operations. Insufficient adaptations will likely result in undue musculotendinous stress and increase the risk of unintentional injury. **Word Count:** 429

Kinematic adaptations with interceptor body armor in Soldiers of the Army 101st

Context: Interceptor body armor (IBA) is critical to the protection of military personnel. The additional weight of the IBA may increase the musculotendinous demands and susceptibility to injury if training requirements have not specifically addressed the extra loads. **Objective:** The purpose of this study was to compare kinematic and force changes with and without IBA during a drop landing task. It was hypothesized that wearing IBA would result in altered landing mechanics and forces. **Design:** A within-subject, repeated measures design was utilized. **Setting:** University sports medicine laboratory. **Patients or Other Participants:** Twenty five 101st Airborne Soldiers participated (Age: 28.2 ± 6.9 years; Height: 1.78 ± 0.07 m; Mass: 82.8 ± 11.6 kg). **Interventions:** A 3D motion analysis and force plate system was used to capture kinematic and force data while subjects performed a single-leg, 50 cm drop landing task. The task was performed under eyes open and eyes closed conditions and with and without IBA. The IBA weighed 13.6 kg and represented the minimum additional weight required to be carried by the Soldiers. **Main Outcome Measures:** The dependent variables were knee flexion and valgus angle at initial contact, maximum knee flexion, time to maximum knee flexion, peak ground reaction forces, time to peak ground reaction forces, and average and peak slope of the ground reaction forces. **Results:** For the eyes opened condition, maximum knee flexion increased (NIBA: 80.9 ± 16.5°; IBA: 91.0 ± 13.4°; $p < 0.001$), time to maximum knee flexion increased (NIBA: 242.3 ± 99.0 ms; IBA: 350.9 ± 217.2 ms; $p = 0.004$), peak ground reaction forces increased (NIBA: 352.2 ± 88.4 %BW; IBA: 378.6 ± 76.0 %BW; $p = 0.011$), time to peak ground reaction forces increased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$), and average slope of peak ground reaction forces decreased (NIBA: 36.3 ± 12.1 ms; IBA: 41.5 ± 8.7 ms; $p = 0.011$). For the eyes closed condition, maximum knee flexion increased (NIBA: 78.9 ± 15.0°; IBA: 85.5 ± 10.8°; $p = 0.001$), time to maximum knee flexion increased (NIBA: 242.0 ± 118.1 ms; IBA: 300.0 ± 80.9 ms; $p = 0.003$), and peak ground reaction forces increased (NIBA: 353.8 ± 80.3 %BW; IBA: 373.6 ± 66.2 %BW; $p = 0.039$). **Conclusions:** Wearing IBA during the drop landing tasks resulted in altered mechanics and ground reaction forces. Proper integration of IBA into training is necessary to ensure musculoskeletal adaptation to carrying the additional loads required of tactical operations. Insufficient adaptations will likely result in undue musculotendinous stress and increase the risk of unintentional injury. **Word Count:** 429

Field and laboratory testing variance and application to daily physical training

Abt JP*, Sell TC*, Nagai T*, House AJ*, Rowe R†, McGrail M†, Lephart SM*: Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, School of Health and Rehabilitation Sciences, University of Pittsburgh, Pittsburgh, PA*; Department of the Army, 101st Airborne Division (Air Assault), Ft Campbell, KY†

Context: Army physical training is often performed at the unit level utilizing similar activities for each soldier regardless of differing musculoskeletal and physiological abilities. The current training format may not most effectively address unit variance to ensure the proper load application or musculoskeletal and physiological progression results. **Objective:** The purpose of this study was to identify the between-subject variance of physical and physiological testing of the 101st Airborne (Air Assault) Division. **Design:** A retrospective cohort design was utilized. **Setting:** University sports medicine laboratory. **Patients or Other Participants:** A total of 111 male and female 101st Airborne (Air Assault) soldiers participated (Age: 28.1 ± 6.8 years; Height: 1.74 ± 0.09 m; Mass: 79.7 ± 14.4 kg). **Interventions:** Subjects performed the standard Army Physical Fitness Test (APFT) and a battery of laboratory assessments consisting of strength, cardiorespiratory, anaerobic, and body composition tests. Isokinetic strength testing was performed on the shoulder, knee, and torso. VO2 max and lactate threshold were measured with a portable metabolic system during an incremental treadmill protocol to exhaustion. Anaerobic power and anaerobic capacity were measured during a 30 second maximal effort sprint on a cycle ergometer. Body composition was measured using air displacement plethysmography. The laboratory testing battery was based on variables that would most contribute to combat readiness and those most likely related to injury in the Army. A coefficient of variation (CV) was calculated for each dependent variable to determine the relative variance for APFT, musculoskeletal, and physiological testing within the Division. **Main Outcome Measures:** The dependent variables were the APFT, peak torque (normalized to body mass) for knee flexion and extension, shoulder internal and external rotation, and torso rotation, VO2 max, anaerobic power and capacity, and percent body fat. **Results:** The CV for the APFT ranged from 13.9-28.1% for the push-up, sit-up, and run components. The CV for strength testing was 32.6% for shoulder internal rotation and 23.5% for shoulder external rotation, 24.8% for knee flexion and 21.6% for knee extension, and 24.7% for the torso. The CV for physiological testing was 37.3% for percent body fat, 18.1% for anaerobic power, 14.3% for anaerobic capacity, and 15.5% for VO2 max. **Conclusions:** The CV for testing ranged from approximately 14-40% indicating a large variance of scores for the APFT, musculoskeletal, and physiological testing. Such variance may support stratified within-unit training that accounts for the different musculoskeletal and physiological abilities, particularly if optimal performance is being sacrificed or high injury rates are observed. Stratified, within-unit training will allow for proper modification of the training stimulus that promotes optimal fitness, without inducing injury. **Word Count:** 425

Validation of the Army 101st Airborne Division (Air Assault) Eagle Tactical Athlete Program

Abt JP*, Sell TC*, Lovalekar M*, Nagai T†, Deluzio JB†, Smalley BW‡, Lephart SM*: *University of Pittsburgh, Neuromuscular Research Laboratory, Pittsburgh, PA; †University of Pittsburgh, Human Performance Research Laboratory, Fort Campbell, KY; ‡Department of the Army, 101st Airborne Division (Air Assault), Division Surgeon's Office, Fort Campbell KY.

Context: Optimal physical readiness of the Army soldier is paramount to tactical operations, performance, and injury prevention. Current research has identified several suboptimal characteristics which necessitate refined physical training. **Objective:** To validate the Eagle Tactical Athlete Program (ETAP) to modify suboptimal strength, performance, and Army Physical Fitness Test variables. **Design:** A randomized controlled trial. **Setting:** A University-operated, military human performance research laboratory. **Patients or Other Participants:** A total of 57 soldiers of the 101st Airborne Division (Air Assault) participated (Experimental- N: 30, age: 25.0 ± 5.2 years, height: 173.4 ± 8.3 cm, mass: 76.6± 11.3 kg, Control- N: 27, age: 25.0 ± 5.8 years, height: 175.6 ± 8.5 cm, mass: 76.5 ± 11.6 kg) participated. **Interventions:** Pre- and post-test measurements were captured for strength, performance, and Army Physical Fitness Test variables. Subjects were randomly assigned to an experimental or control group. The experimental group performed an eight week clinical trial of ETAP, which was based on the results from 21 months of laboratory data collected on soldiers of the 101st Airborne Division. ETAP followed a sports medicine periodized training model and included specific modalities designed to improve athleticism. The periodized training program was also developed to specifically address and maximize each athletic and skill-related performance component to ensure the tactical athletes are a viable force for deployment into the demands of the current conflict. The control group performed standard physical training according to FM 3-22.20. This trial was designed to induce adaptations in variables known to contribute to injury and limit performance. **Main Outcome Measures:** Knee, shoulder, and torso strength, body fat, anaerobic power and capacity, performance tests, and the Army Physical Fitness Test. Two way repeated measures ANOVA tests were used to analyze the dependent variables. **Results:** Compared to the control group, soldiers performing ETAP demonstrated significant improvements ($p < 0.05$) in knee extension strength (pre: 236.0 ± 48.9 %BW, post: 244.1 ± 42.3 %BW), torso strength (pre: 128.5 ± 33.5 %BW, post: 137.6 ± 27.4 %BW), 2-minute sit-ups (pre: 58.9 ± 13.3 repetitions, post: 68.0 ± 10.0 repetitions), 2-mile run (pre: 16.6 ± 2.4 minutes, post: 15.4 ± 2.0 minutes), agility (pre: 5.37 ± 0.45 seconds, post: 5.25 ± 0.38 seconds), 300 yard shuttle (pre: 69.2 ± 6.22 seconds, post: 66.8 ± 6.3 seconds), and anaerobic power (pre: 11.9 ± 2.3 w/kg, post: 13.9 ± 2.4 w/kg). **Conclusions:** Soldiers performing ETAP demonstrated significant improvements in variables that are vital to physical readiness, improving the athleticism of the soldier, and reducing the likelihood of musculoskeletal injury. The observed training adaptations should have long-term implications to improve physical readiness of the soldier when ETAP is periodized across a 10-12 month pre-deployment cycle. **Word Count:** 442

Knee Biomechanics in Air Assault Soldiers Performing Two-Legged Drop Landings with and without Visual Input

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Landing tasks commonly result in non-contact knee ligament injuries and are widely performed in military training and operations. Previous civilian research has demonstrated mixed results on the effects of visual input availability on landing performance. Soldiers are frequently required to perform landings without sufficient visual input and although data are not available for tactical exercises specifically performed by air assault soldiers, night time tactical maneuvers increase the risk of injury two fold. **PURPOSE:** To determine the differences in knee landing kinematics and vertical ground reaction forces (VGRF) of air assault soldiers with and without visual input. **METHODS:** A total of 110 male air assault soldiers (28.7±7.1 yrs, 177.2±7.2 cm, 83.6±12.8 kg) participated. Subjects performed a two-legged drop landing task from a 50 cm platform onto two force plates. Six high-speed infrared cameras tracked the trajectories of the reflective markers attached to subjects' lower extremities. Subjects performed three trials each with visual input and blindfolded. Knee flexion angle, knee valgus angle, and VGRFs (normalized to body weight) were compared between conditions with dependent t-tests. **RESULTS:** No significant differences in knee flexion and valgus angles were detected at initial foot contact. When blindfolded, maximum knee flexion was less (right: 89±20° vs. 85±20°, $p<0.001$; left: 89±19° vs. 86±20°, $p<0.001$), maximum VGRF of the left foot was greater (333.9±88.9%BW vs. 351.5±83.3%BW, $p=0.001$), and time elapsed from initial foot contact to maximum VGRF of the left foot was longer (0.374±0.10 vs. 0.394±0.09 s, $p=0.022$). **CONCLUSION:** Diminished visual acuity caused the subjects to alter their landing strategy for the two-legged drop landing task. While the greater VGRF of the left foot may pose greater risk of injury, soldiers are able to dissipate the force by prolonging the time from initial foot contact to peak VGRF. Significant differences found only with the left leg raises the question whether landing strategies change based on the availability of visual input, perhaps increasing asymmetrical or preferable joint loads.

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Clinically Significant Side-to-Side Lower Extremity Strength Asymmetries in US Army 101st Airborne Soldiers

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Side-to-side (S-S) symmetry of lower extremity (LE) muscle strength is important for preventing between-limb compensations that overload one side and increase injury risk. As such, S-S comparisons in LE strength are frequently made in injury prevention and rehabilitation contexts. Past work consistently shows S-S LE strength differences <10% are normal in athletes. However, S-S LE strength differences in large military samples have not been previously reported. Considering the healthcare burden of unintentional musculoskeletal injuries, characterizing the S-S LE strength differences in Soldiers will give data of the frequency of potentially dangerous S-S muscle imbalance. This data can then be used to screen for future risk of new LE injury or re-injury. **PURPOSE:** To describe the prevalence of clinically significant S-S asymmetry (S-S difference >10%) in LE strength of Soldiers. **METHODS:** Fully operational male US Army 101st Airborne Soldiers (n=402; age 28.1 ± 6.6yr; height 177.7 ± 7.1cm; mass 84.1 ± 12.5kg) were tested. An isokinetic dynamometer measured concentric quadriceps (QUAD) and hamstring (HAM) mean peak torque (Nm/kg, 5 reciprocal repetitions, 60°/sec), and isometric hip abductor (ABD) mean peak force (N/kg, 3 reciprocal repetitions, 5 sec/effort). A handheld dynamometer measured isometric ankle eversion (EV) and inversion (INV) mean peak force (kg, 3 repetitions, 5 secs/effort). Counts were made of Soldiers with S-S differences >10% (designated ‘suprathreshold’(ST)) and proportions calculated. **RESULTS:** For QUAD and HAM strength, 41% had S-S differences >10% (ST range=11-50%). For ABD strength, 38% had S-S differences >10% (ST range=11-53%). For EV strength, 34% had S-S differences >10% (ST range=11-37.5%). For INV strength, 37% has S-S differences >10% (ST range=11-40%). **CONCLUSION:** A large proportion of Soldiers (>33%) had S-S leg strength differences >10% (maximum S-S difference=53%). Consideration should be given to correction of S-S imbalances via targeted training programs. Such intervention may contribute to reducing the risk of sustaining new unintentional LE injury or re-injury, and enhance Soldiers’ ability to safely and effectively execute mission essential tasks.

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Lower body fat improves physical and physiological performance in Army soldiers

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In the Army the maximal allowable percent body fat varies depending on gender and age, ranging between 30-36% for female and 20-26% for male. However, the Army Weight Control Program policy stipulates all soldiers are encouraged to achieve the more stringent Department of Defense (DOD) goal, which is 18% body fat for males and 26% for females.
PURPOSE: To determine if active duty soldiers who meet the DOD body fat goals perform better on physiological, musculoskeletal, and Army Physical Fitness tests (APFT) compared to soldiers who exceed the standards. **METHODS:** A total of 99 male 101st Airborne Division (Air Assault) soldiers (age=28$\pm$7.0 years, height= 177$\pm$7.4 m, weight= 82.9$\pm$12.4 kg) participated. Percent body fat (%BF) was assessed using air-displacement plethysmography. Based on the %BF, subjects were assigned to group 1 (body fat $\leq$ 18%) or group 2 (body fat > 18%). Subjects completed a series of physical performance tests consisting of anaerobic power, anaerobic capacity, maximal oxygen consumption (VO2max), push-ups, sit-ups, two mile timed run test, shoulder internal and external rotation strength, and knee flexion and extension strength. **RESULTS:** The mean %BF was 13.3±3.7% (group 1) and 25.8±5.2% (group 2). Subjects who met the DOD body fat goals (group 1) performed significantly better on seven of the 10 physical fitness tests including anaerobic capacity (8.3±0.6 w/kg; 7.2±1.0 w/kg; $p \leq 0.001$), VO2max (52.2±5.4 ml/kg/min; 44.1± 6.8 ml/kg/min; $p \leq 0.001$), push-ups (78.2±18.5 reps; 65.7± 13.9 reps; p=0.002), shoulder internal rotation (66.1±16.2 N/kg; 50.4$\pm$14.5 N/kg; $p \leq 0.001$) and external rotation strength (45.4±7.7 N/kg vs. 36.6±7.4 N/kg; $p \leq 0.001$), and knee flexion (127.9±23.9; 103.6±26.6; $p \leq 0.001$) and extension strength (263.5±49.0 N/kg; 219.0±41.7 N/kg; $p \leq 0.001$). **CONCLUSION:** Soldiers who met the DOD %BF goals performed better on physiological, musculoskeletal and Army APFT than soldiers who exceeded the standards. The higher performance on military physical readiness tests by soldiers with a lower percent body fat substantiates the need to continue to enforce stringent body fat standards for Army personnel in order to optimize military readiness.

Dietary Habits of Soldiers of 101st Airborne Division Air Assault

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Proper nutrition plays an important role in maximizing a Soldier's ability to meet the demands of physical and tactical training. **PURPOSE:** To evaluate dietary habits of 101st Airborne Division (Air Assault) (101st ABN DIV (AA)) Soldiers.
METHODS: A total of 367 101st ABN DIV (AA) Soldiers (female 57=; male n= 310; Age 27.9+6.5 years) completed a detailed diet history including eating habits, food and fluid intake before during and after physical training, and dietary supplement use. A 24 hour recall was collected (n=293; female=52, male =241) and analyzed using Food Processer SQL 10.6 (ESHA) to assess macro- and micronutrient content of the diet. **RESULTS:** Soldiers consumed 3.4±1.0 meals per day with 25% of Soldiers skipping at least one meal per day. Soldiers reported eating out 4.4±5.6 meals per week (range, 0-31 meals). Carbohydrate intake was 304±145 g/day (3.8 g/kg body weight), protein 111±57 g/day (1.4 g/kg body weight), and fat 91±53 g/day with 60% of Soldiers consumed greater than 30% of calories from fat. Fluids were consumed by 76% of Soldiers before physical training (PT), 70% during PT, and 98% following PT. Food was consumed by 30% of Soldiers before PT, whereas 93% consume food following PT (35% within 1 hour, 64% 1-2h, 1% > 3 h) with 77% eating a snack or meal with both carbohydrate and protein. Use of at least one dietary supplement was reported by 41% of the Soldiers (43% vitamin/mineral, 22% protein-energy drinks, 8% joint health, 7% nitric oxide, 5% each amino acids, antioxidants, weight loss). **CONCLUSION:** Our findings suggest that Soldiers of the 101st practice adequate hydration before, during and after exercise. It is recommended that Soldiers increase daily carbohydrate and protein intake and reduce total fat intake, eat at least 3 meals per day, including either a meal or snack prior to PT to optimize performance. Although the majority of Soldiers consume a sufficient post training snack to aid in recovery, low daily carbohydrate intake does not promote maximal fuel restoration. Future research should focus both on evaluating the macronutrient content of the diet that optimizes Soldier performance and on approaches to educate Soldiers on how to incorporate these nutrition guidelines into their daily eating.

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Dietary Supplement Habits of Soldiers of 101st Airborne Division Air Assault

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To achieve optimal military readiness, Soldiers are turning to dietary supplements (DS) to increase strength, endurance, alertness and overall health. **PURPOSE:** Evaluate DS habits of 101st Airborne Division (Air Assault) (101st ABN DIV (AA)) Soldiers. **METHODS:** A total of 390 Soldiers completed a diet history including a detailed DS questionnaire. **RESULTS:** Sixty-one percent (n=236; Age 29.0 ±6.6 years; BMI 26.7 ± 3.4 kg/m2) of Soldiers consume at least one DS, of these 58% consume multivitamin supplements (MV), 32% whey protein, 16% energy drinks, 10% creatine and 10% nitric oxide (Table 1).

Table 1: Dietary Supplement Use, Perceived Benefits and Adverse Reactions

Supplement	Purpose of Use	Usage	Perceived Benefit	Adverse Reaction
MV	Supplement diet & improve health Improve performance Improve joint health	Military Training (MT) 52% Deployed (DP) 24% Both 24%	More energy/less fatigue Fewer colds Increase well being	Nausea
Whey	Increase muscle mass, strength, recovery Improve performance Supplement diet and improve health	MT 53% DP 25% Both 16%	Increase muscle mass Recovery Weight/body fat loss	Decrease appetite Weight gain
Energy Drink	Improve physical performance Improve cognitive function Improve joint health	MT 37% DP 34% Both 29%	Feel more energized Alertness Stay awake	Jittery feeling Dehydration Indigestion Crashing feeling Dependency
Creatine	Increase muscle mass, strength, recovery. Improve performance Supplement diet and improve health	MT 50% DP 29% Both 17% N/A 4%	Increase work out duration/intensity Increase muscle strength, size, endurance	Upset stomach Dehydration
Nitric Oxide	Increase muscle mass, strength, recovery. Improve physical	MT 53% DP 18% Both 18% N/A 11%	Increase energy to workout Less muscle	None reported

	performance Supplement diet and improve health		soreness Improve quality of workout	

CONCLUSION: Soldiers are using DS to correct nutrient inadequacies and improve the quality of the daily diet, in order to optimize adaptations from training, expedite recovery and improve health and physical readiness. Future efforts should focus on educating Soldiers to use foods, fluids and nutrient timing as a safer and more effective alternative to DS.

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Dietary Intake of Army Soldiers in Occupation Specialties Requiring Heavy Physical Demands: 1990: Board #185 June 2 9:00 AM - 10:30 AM

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(No relationships reported)

Training and operational demands of Soldiers have been likened to those of elite athletes, with similar performance and nutrition needs. Dietary recommendations have been developed for the optimal amount of carbohydrate (CHO), protein (PRO), and fat to fuel athletes involved in heavy physical training. The same recommendations may be used as a guide for soldiers with high physical demands to ensure proper nutrition to optimize physical readiness, performance, and health.

PURPOSE: To evaluate the dietary intakes of Soldiers with a military occupation specialty (MOS) requiring heavy physical demands.

METHODS: A total of 205 Soldiers of the 101st Airborne Division (Air Assault) volunteered (age: 26.5±5.4 years, height: 1.74±0.08 m, weight: 80.7±14.2 kg). All soldiers had a MOS with a physical demands rating (PDR) of moderately heavy to very heavy and completed a 24 hour diet recall. Army Pamphlet 611-21 served as the reference for PDR of specified MOS. Intake was assessed using a dietary analysis software program. Data was reported using median and interquartile range (Q1-Q3).

RESULTS: Calorie (CAL), PRO, CHO, and fat intake was 2,433 kcal (1,772.5-3,048.5 kcal), 101g (76-136g), 279g (195.5-378.5g), and 82g (55-112g) respectively. Soldiers consumed 17% (14-21%) of CAL from PRO, 49% (42-58%) of CAL from CHO, and 33% (25.5-38%) of CAL from fat. The amount of PRO consumed per kg of body weight was 1.29 g/kg (0.90-1.69g/kg) and CHO consumed per kg of body weight was 3.6 g/kg (2.55-4.85g/kg). Ninety percent of Soldiers fell below the recommended CHO intake of at least 7g/kg of body weight (recommendation for individuals engaging in 1-1/2 hours training per day), 87% fell outside the recommended PRO intake of 1.6-1.7g/kg body weight, and 60% consumed >30% of their CAL from fat.

CONCLUSIONS: These results indicate that Soldiers in a MOS with heavy physical demands may be sub-optimally fueling to meet nutrition needs. To optimize physical readiness, performance, and health Soldiers need to consume enough CHO and PRO to support training and tactical demands while at the same time reducing fat intake. Future research should examine the best methods to modify eating habits to meet the demands of physical training to optimize health, performance, and physical readiness.

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Optimal Body Composition For Performance of 101St Airborne (Air Assault) Soldiers

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Abstract:
Research has shown that Soldiers meeting the Department of Defense body fat (BF) standard of ≤18% perform significantly better on a majority of physical fitness tests than those not achieving the standard. Questions remain about the BF threshold for optimal performance on various fitness tests of 101st Airborne (Air Assault) Soldiers.

PURPOSE: To assess the relationship between BF threshold and performance on tests of anaerobic power, aerobic capacity, and strength in order to determine body composition for optimal performance.

METHODS: Data from 153 male Soldiers of the 101st Airborne Division (Air Assault) was analyzed (age=28.5±7.0 yrs, height=1.79±.07 m, mass=86.2±13.4 kg). Each Soldier underwent tests of mean and peak anaerobic power (MAnP & PAnP), maximal oxygen uptake (VO_2 max), and bilateral isokinetic strength testing of knee flexion/extension, shoulder internal/external rotation, and torso rotation. Body fat was determined with air displacement plethysmography. Maximal VO_2, MAnP, PAnP, and cumulative strength (CS) rank were each plotted against BF and a best fit line was used to determine an inflection point for BF threshold. An independent t-test was calculated to determine significant differences between scores above and below each BF inflection point, and Spearman's Rho was used to determine relationships between BF and performance.

RESULTS: Body fat was correlated with MAnP (r=-.646, p<0.01), PAnP (r=-.174, p<0.01), VO_2max (r=-.731, p<0.01), and CS rank(r=.541, p<0.01). Best fit lines indicated inflection points at 18% BF for MAnP and PAnP and at 14% BF for CS rank. Body fat had an inverse linear relationship with VO_2max. Mean anaerobic power was higher for Soldiers with BF <18% (8.2±0.66 versus 7.2±0.97 W/kg, p<0.01) and CS rank was higher for Soldiers with BF <14% (55.9±31.4 versus 84.9±36.2, p<0.01). There was no difference between groups for peak anaerobic power.

CONCLUSIONS: While BF and VO_2max had a linear relationship, a BF threshold may exist for MAnP and CS rank where an increase in BF decreases performance. Although a BF threshold was present for PAnP, the lack of distinction between groups may indicate that a variable independent of BF might also predict power performance. These findings provide insight in determining optimal body composition for task-specific physical readiness.

Landing Impact, Hip Kinematics, and Hip Strength Predict Dynamic Postural Stability in Army 101st Airborne

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Postural instability contributes to unintentional lower extremity musculoskeletal injury. It is unclear if reported contributors to knee injury influence dynamic postural stability. **PURPOSE:** To determine if peak vertical ground reaction force (vGRF), sagittal and frontal plane knee and hip kinematics at initial contact, knee flexor/extensor strength, and hip abductor/adductor strength significantly predict dynamic postural stability index (DPSI). **METHODS:** Thirty nine male Army 101st Airborne (Air Assault) soldiers participated (26.3±5.6 yrs, 176.9±8.5 cm, 81.0±17.7 kg). Three dimensional kinematic and ground reaction forces (GRFs) were captured with a motion capture system interfaced with a force plate. Subjects performed a double-leg forward jump over a 12" hurdle with a single-leg landing on a force plate positioned at a distance of 40% subject height. Subjects landed on the dominant limb, stabilized as quickly as possible, and maintained single-leg balance with hands at the waist. DPSI was calculated using three dimensional GRFs from the first three seconds following initial contact. Isokinetic knee strength at 60^o/sec and side-lying isometric hip strength at 10^o hip abduction were tested using a multi-mode dynamometer. Strength and peak vGRF were normalized to % body weight. A stepwise multiple linear regression was performed to determine if the independent variables significantly predicted DPSI. The F probability for variable entry of .05, F probability for variable removal of .10, and alpha level of .05 for model significance was set a priori. **RESULTS:** Significant predictors in the linear regression model of DPSI include peak vGRF, hip abduction strength, and hip flexion/extension angle at initial contact ($p < .001$; $R^2 = .88$; respective β=.0001, -.0013, .0018; constant=.0141). **CONCLUSIONS:** Dynamic postural stability for soldiers of the Army 101st Airborne (Air Assault) may be optimized by decreasing landing impact, increasing hip abduction strength, and increasing hip flexion at initial contact during landing tasks. Current injury prevention strategies targeting the significant knee injury contributors may concurrently benefit dynamic postural stability. Investigations are warranted to assess effects of training targeting the hip on dynamic postural stability.

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Title: 15 words

The Relationship among Body Composition, Anaerobic Power, Lactate Threshold and Maximal Oxygen Consumption in Male Soldiers

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Context: Suboptimal levels of body composition, anaerobic power, lactate threshold, and maximal oxygen consumption have been directly linked to an increased risk of injury and impaired performance as premature fatigue results. However, the relationships among these parameters in a military population have not been studied and may vary depending on occupational demands. **Objective:** To determine whether a significant relationship exists among body composition, anaerobic power, lactate threshold, and maximal oxygen consumption in male soldiers of Army 101st Airborne when stratified according to the Military Occupation Specialty's Physical Demand Ratings (PDR). **Design:** Descriptive cross-sectional study design. **Setting:** University sports medicine laboratory. **Participants:** Forty healthy 101st Airborne (Air Assault) soldiers (29 ± 6.8 yrs, 184 ± 25.9 cm, 70 ± 2.3 kg) participated. They were grouped according to PDR by moderate (n = 8), moderately heavy (n = 7), and very heavy (n = 25). **Interventions:** The subjects were tested on two separate days. Body composition was measured with an air-displacement plethysmography device, and Wingate cycle ergometer protocol was used to measure peak and mean anaerobic power. An incremental ramp protocol was used to capture maximal oxygen consumption and lactate threshold. **Main Outcome Measures:** Body composition (BC) was measured in percentage of body fat. Peak and mean anaerobic power (PNAP and MNAP) were measured in Watts and normalized to body weight (Watt/kg). Maximal oxygen consumption (VO_2max) was measured in milliliter per kilogram per minute (ml/kg/min). Lactate threshold was calculated in percentage of maximal oxygen consumption ($LTVO_2$). **Results:** For soldiers with PDR of moderate, PNAP was significantly correlated to MNAP (r = .766, p = .027) and VO_2max (r = .853, p = .031). For soldiers with PDR of moderately heavy, BC was significantly correlated to MNAP (r = -.800, p = .031) and VO_2max (r = -.825, p = .022). MNAP was significantly correlated to VO_2max (r = .774, p = .041) and $LTVO_2$ (r = -.931, p = .002). For soldiers with PDR of very heavy, BC was significantly correlated to MNAP (r = -.532, p = .007) and VO_2max (r = -.665, p = .001). MNAP was significantly correlated to PNAP (r = .786, p < .001) and VO_2max (r = .614, p = .002). **Conclusions:** There were selected relationships among body composition, anaerobic power, lactate threshold, and maximal oxygen consumption in male soldiers of Army 101st Airborne when stratified according to their PDR. However, not every group shared the same relationships among variables. Despite similar grouping, the specific demands within a group may vary and account for the different demonstrated relationships between groups. Future studies should focus on determining the causes of such differences. **Word Count:** 435

Physiological Differences between Male and Female Army Soldiers Matched on Age and Years of Service

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US Army Soldiers must optimize physical readiness to minimize the risk of unintentional musculoskeletal injury and optimize performance. All Soldiers follow similar physical training (PT) guidelines and perform gender-integrated PT. In order to optimize performance, male and female athletes train differently; therefore it is possible that traditional PT may not specifically address the unique physical and physiological needs of female Soldiers. **PURPOSE:** To determine if physiological differences exist between genders in US Army Soldiers of the 101st Airborne Division (Air Assault), controlling for age and years of service (YOS). **METHODS:** Data were collected on 53 female Soldiers (age= 25.8± 4.4 years, height= 1.65±0.06 m, mass= 65.9±10.3 kg) and matched with 53 male Soldiers (age= 25.5±4.2 years, height= 1.76±0.06 m, mass=83.5±13.6 kg) based on age (±3 years) and YOS (± 0.5 years). Variables analyzed were: percent body fat, total mass, lean mass, and fat mass; anaerobic power (AP)/capacity (AC); and maximal oxygen uptake (VO_{2max})/lactate threshold (LT). Paired *t*-tests were used to compare all variables between genders. Statistical significance was set at $p<0.05$ *a priori*. **RESULTS:** Female Soldiers demonstrated significantly higher %BF (F: 27.4±6.0%; M: 21.2±8.4%) and significantly lower total mass (F: 65.9±10.3 kg; M: 83.5±13.6 kg), lean mass (F: 47.6± 6.4 kg; M: 65.0± 8.0 kg), AP (F: 9.3±1.4W/kg; M: 13.6±2.0W/kg), AC (F: 5.9±1.1W/kg; M: 7.8±0.9W/kg), VO_{2max} (F: 39.6±5.4 ml/kg/min; M: 46.6±7.0 ml/kg/min), and VO_2 at LT (F: 33.3±5.3 ml/kg/min; M: 38.2±7.0 ml/kg/min), (all, $p<0.001$).**CONCLUSIONS:** Gender differences in physiological variables do exist in US Army Soldiers of the 101st Airborne Division (Air Assault). These differences have important implications for potential changes or augmentation to current PT in order to optimize physical performance. Future research should investigate other physical characteristics that may relate to injury and if targeted PT that addresses the identified suboptimal characteristics in female Soldiers mitigates the risk of unintentional musculoskeletal injury and optimizes physical readiness.
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Strength Differences between Male and Female Soldiers of the 101st Airborne Division (Air Assault)

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Context: In the US Army, male and female Soldiers participate in gender-neutral physical training and may have similar physical demands during occupational and operational tasks. Musculoskeletal injuries, many of which may be preventable, are the primary reason for seeking medical care among military personnel and may be related to suboptimal musculoskeletal characteristics, which may result in higher injury rates in female Soldiers. **Objective:** To determine if strength differences exist between genders in US Army Soldiers of the 101st Airborne Division (Air Assault) matched on age and years of service (YOS). **Design:** Cross-sectional study. **Setting:** Research laboratory. **Participants:** Data were collected on 65 female Soldiers (age=26.9±5.7 years, height=1.65±0.06 m, mass=65.7±9.8 kg) and 65 male Soldiers (age=26.9±5.8 years, height=1.76±0.07 m, mass=82.3±12.7 kg) matched on age (±2 years) and YOS (± 1.0 years). All subjects were free of current medical or musculoskeletal conditions that prevented full active duty. **Interventions:** Isokinetic knee flexion/extension (FLEX/EXT), shoulder internal/external rotation (IR/ER), and torso rotation (ROT) strength was assessed using an isokinetic dynamometer (5 repetitions each, 60°/sec). Isometric hip abduction/adduction (ABD/ADD) strength was assessed with three, 5 sec alternating contractions using an isokinetic dynamometer. Isometric ankle inversion/eversion (IN/EV) and plantarflexion/dorsiflexion (PF/DF) strength was assessed using a handheld dynamometer (3 repetitions). All tests were performed on the right side. Paired *t*-tests were used to compare normally distributed variables and Wilcoxon signed rank tests were use to compare non-normally distributed variables. Statistical significance was set at p<0.05 *a priori*. **Main Outcome Measures:** Peak torque was averaged normalized to body weight (%BW) for: shoulder IR/ER, knee FLEX/EXT, torso ROT, and hip ABD/ADD. Average peak force (kg) was calculated for ankle IN/EV and PF/DF. **Results**: Female Soldiers demonstrated significantly less strength in shoulder IR (F: 35.8±8.9 %BW; M: 61.3±15.1 %BW), shoulder ER (F: 29.5±5.2 %BW; M: 43.7±9.7 %BW), knee FLEX (F: 92.9±20.9 %BW; M: 116.8±30.1 %BW), knee EXT (F: 189.5±36.9 %BW; M: 241.6±55.4 %BW), torso ROT (F: 105.8±25.3 %BW; M: 150.9±29.2 %BW), ankle IN (F: 25.2±6.8 kg; M: 34.3±7.5 kg), and ankle EV (F: 22.3±6.0 kg; M: 30.7±6.3 kg), (all, p<0.001). **Conclusions:** Strength differences do exist between male and female Soldiers, with female Soldiers demonstrating less shoulder, knee, ankle, and torso strength. No gender differences were noted in hip strength or ankle PF/DF; however it is unclear if this is due to adequate strength in female Soldiers or inadequate strength in male Soldiers and should be explored further. Future research should explore if these differences contribute to unintentional musculoskeletal injury and decreased physical readiness as well as if these differences can be mitigated through gender-specific physical training.

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Comparison of self-reported musculoskeletal injury history between female and male US Army Soldiers

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Background/ Purpose: Musculoskeletal injuries can adversely impact performance and certain injuries are risk factors for recurrence of the injury. The aim of this analysis was to compare the proportion of female and male US Army Soldiers with a self-reported history of musculoskeletal injury.

Methods: Self-reported musculoskeletal injury history for a period of two years was obtained from 296 Soldiers (age = 27.8 ± 6.5 years, 12.2% female). Injuries were classified according to their anatomic location and injury type (traumatic vs. overuse). Proportions of subjects with injuries were compared using Fisher's exact test.

Results: Age was not significantly different between genders (females 27.0 ± 6.0 years, males 27.9 ± 6.6 years, $p = 0.440$). A greater proportion of females reported a musculoskeletal injury compared to males (41.7% and 28.1% respectively, $p = 0.119$), though this difference was not statistically significant. A greater proportion of females than males reported a lower extremity injury (27.8%, 13.8%, $p = 0.046$) and a knee injury (11.1%, 2.7%, $p = 0.033$). There was no difference in the proportion of females and males reporting an upper extremity injury (5.6%, 7.7%, $p = 1.000$). Interestingly, a greater proportion of females than males reported an overuse injury (22.2%, 8.8%, $p = 0.036$).

Conclusions: Examination of potential physiological, musculoskeletal, biomechanical and nutritional risk factors in these subjects is necessary. There may be a need to implement a customized program to prevent recurrence of certain lower extremity and overuse injuries in female Soldiers, and to prevent an adverse impact on performance.

Measuring self-reported recall of unintentional musculoskeletal injuries in an Army Airborne Division

Monday, October 29, 2012

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Background/Purpose: Self-reported data are often used in epidemiology, but self-reported recall of comprehensive injury data has not been measured among soldiers. The aim of this analysis was to assess self-reported recall of unintentional musculoskeletal injuries among soldiers in an Army Airborne Division.

Methods: Self-reported and medical chart-reviewed injuries among 115 soldiers (age 26.6 ± 5.8 years (mean ± SD), 87.0% male) were matched by anatomic location, side (for extremity injuries), year, and type. The injuries included in the analysis were those that had occurred during the year of survey (recent injuries), and during the preceding calendar year (old injuries). Recall was expressed as the percent of medical chart-reviewed injuries correctly recalled in the self-report. Proportions were compared using the Fisher's exact test.

Results/Outcomes: Eighty-seven injuries were recorded in the medical charts. Common injury types were pain/spasm/ache (29/87, 33.3% of the injuries), sprain (18/87, 20.7%), and strain (15/87, 17.2%). Overall, recall was low (9/87 = 10.3%). Recall was higher for severe injuries (traumatic/stress fractures, 1/4 = 25.0%) as compared to less severe injuries (non-fracture injuries, 8/83 = 9.6%), but the difference was not statistically significant ($p = 0.359$). Recall was

higher for recent injuries (3/26 = 11.5%) as compared to old injuries (6/61 = 9.8%), but the difference was not statistically significant ($p = 1.000$).

Conclusion: The low self-reported recall in this study underscores the need for further investigation of factors affecting recall and strategies to improve accuracy of recall of injury data in various military populations.

Shoulder Flexibility and Strength Predict Dynamic Pushup Ratio in the 101st Airborne Division Soldiers

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Functional exercises such as an unstable-surface push-up are hypothesized to promote enhanced joint kinesthesia and muscular co-contraction to increase shoulder joint stability. Previous research has reported the benefits of using unstable-surface push-ups on upper body strength, trunk stability, and balance. Our preliminary work has demonstrated that individuals perform half less unstable-surface push-ups as stable-surface push-ups during a thirty second time period. We have hypothesized that individual's ability to perform unstable-surface push-up might be associated with shoulder and trunk rotation strength and flexibility. **PURPOSE:** To evaluate shoulder and trunk rotation strength and flexibility to predict unstable-surface push-up performance. **METHODS:** A total of 140 active duty soldiers were recruited from the Army 101st Airborne Division (27.8±6.9yrs, 175.1±8.4cm, 79.2±14.3kg). Subjects were instructed to perform as many unstable-surface push-ups as possible during a thirty second test period, followed by three minutes of rest and stable-surface push-up test during a thirty second test period. Dynamic push-up ratio (DPR) is the ratio of unstable-surface push-ups performed divided by stable-surface push-ups performed. A standard goniometer was used to measure the following flexibility: shoulder flexion/extension, abduction, and internal/external rotation. An isokinetic dynamometer was used to evaluate shoulder internal-external rotation, abduction-adduction, and trunk rotation peak torque at 60^{o}/sec and trunk rotation flexibility. Predictor variables (flexibility, strength, and strength ratio) were entered in a stepwise multiple linear regression to predict DPR. **RESULTS:** Significant predictors of DPR in the linear regression model include shoulder abduction peak torque, shoulder external rotation flexibility, and shoulder abduction-adduction peak torque ratio ($p<0.001$, $R^2=0.277$). **CONCLUSION:** Shoulder abduction and adduction strength may be focused on training to enhance DPR. However, those predictor variables can only explain 27.7% of the variance on DPR, and other neuromuscular characteristics such as proprioception, proper shoulder biomechanics, muscle activation patterns, and dynamic balance at the shoulder joint should be evaluated in future study.

Changes in Physical and Physiological Characteristics after Deployment to Afghanistan

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Soldiers of the 101st Airborne Division (Air Assault) have experienced multiple deployments in recent years. Deployment missions and combat environment change constantly for each deployment. It is essential to understand the physical and physiological impact of deployment.

Purpose: To assess changes in physical and physiological characteristics during deployment to Afghanistan.

Methods: A total of 35 active duty Soldiers from the 101st Airborne Division (Air Assault) volunteered (Age: 24.8 ± 4.9 years; Height: 174.4 ± 8.6 cm; Mass: 76.6 ± 13.7 kg; Pre Test-Deployment: 207 ± 76 days; Deployment: 350 ± 18 days; Deployment-Post Test: 19 ± 18 days). Testing consisted of body mass (kg), body composition (%BF), eyes-closed single-leg balance (N), knee flexion/extension and ankle inversion/eversion strength (%BW), anaerobic power/capacity (W/kg), and aerobic capacity (ml/kg/min) and lactate threshold (%VO_{2max}). Paired t-tests with p-value of 0.05 were used for statistical analysis.

Results: Anaerobic power (Pre: 11.7 ± 2.5 W/kg, Post: 12.5 ± 2.6 W/kg, $p = 0.019$) and lactate threshold (Pre: 77.1 ± 8.9 %VO_{2max}, Post: 82.0 ± 7.7 %VO_{2max}, $p = 0.016$) increased significantly post-deployment. Eyes-closed single-leg balance in medial-lateral direction (Pre: 7.9 ± 3.6 N, Post: 9.7 ± 5.8 N, $p = 0.032$) and isometric ankle eversion strength (Pre: 42.8 ± 9.6 %BW, Post: 36.4 ± 7.0 %BW, $p = 0.001$) worsened significantly post-deployment.

Conclusions: The current study has demonstrated changes during an Afghanistan deployment for various physical and physiological characteristics. Soldiers could utilize the results of this study to augment training prior to and while deployed. Specific exercises such as balance and ankle strengthening exercises may minimize the physical and physiological changes and assist with musculoskeletal injury prevention while deployed.

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KNEE PROPRIOCEPTION AND STRENGTH CORRELATE TO KNEE FLEXION ANGLE DURING A LANDING TASK

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Context: Tactical performance and prevention of knee injuries during dynamic landing tasks requires afferent information from joint mechanoreceptors about joint position, kinesthesia, and sense of heaviness, as well as adequate muscular strength to attenuate large impact forces. In order to design better physical fitness training for the Soldiers and to minimize unintentional musculoskeletal injuries, understanding the relationship between those variables would be beneficial. **Objective:** To investigate the relationship between knee proprioception, strength, and knee flexion angle during a landing task. **Design:** Descriptive Laboratory Study. **Settings:** Human Performance Research Laboratory. **Patients or Other Participants:** Convenient sample of 50 healthy male Soldiers of the 101st Airborne Division (Age: 26.4±5.8 yrs; Height: 176.5±8.0 cm; Mass: 79.8±16.6 kg). **Interventions:** Knee flexion and extension conscious proprioception measured as threshold to detect passive motion (TTDPM) was performed on an isokinetic dynamometer at 45° flexion and 0.25°/s. Subjects wore a compression boot, were blindfold, and listened to static noise in order to eliminate extraneous cues. Subjects were instructed to press a stop-button when they first felt limb movement and were then able to detect the direction of movement. The arc between the initial and final positions was reported as TTDPM. Subjects performed a total of five trials for each direction (order of direction was randomized). Isometric knee extension and flexion strength was evaluated at 45° flexion with the isokinetic dynamometer. Landing kinematics were evaluated using a 3D motion analysis system while subjects performed three single-leg stop-jumps at a distance 40% of their height from the force plate. Knee flexion angles at initial contact and maximum knee flexion angle were calculated. **Main Outcome Measurements:** TTDPM toward flexion and extension direction, isometric knee extension and flexion strength, knee flexion angles at initial contact and maximum knee flexion angles during a single-leg stop-jump task. Due to the nature of TTDPM data (positively skewed), a nonparametric correlation, Spearman's rho, was used to evaluate the relationship. P-value was set at 0.05. **Results:** The following pairs were significant: TTDPM and initial knee flexion (TTDPM Flexion: rho = -0.318, p=0.024; TTDPM Extension: rho = -0.349, p=0.013), knee strength and knee flexion angle at initial contact

(Flexion Strength: rho=0.392, p=0.005; Extension Strength: rho=0.335, p=0.018), and knee strength and peak knee flexion angle (Flexion Strength: rho=0.447, p=0.001; Extension Strength: rho=0.465, p=0.001). **<u>Conclusions</u>:** Enhanced knee proprioception and increased knee strength was associated with greater knee flexion angle at initial contact. Greater knee extensor strength was also associated with peak knee flexion. Greater initial and peak flexion can attenuate the landing impact far greater than the extended knee. Collectively, enhanced proprioception, greater knee strength, and greater initial and peak knee flexion are inter-related and may play a vital role in unintentional musculoskeletal injury prevention for the Army Soldiers. **<u>Word Count</u>:** 449

Measurement of Spinal Active Range of Motion among Different Military Occupations in Combat Aviation Brigade

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Context: A high incidence of low back and neck pain is reported in aviators and crews who ride in helicopters. Limited low back and cervical range of motion (ROM) are reported risk factors for low back and neck pain. It is unknown if spinal ROM differs between air-based military occupational specialty (MOS) and ground-based MOS. **Objective:** To compare cervical, thoracic, and lumbar spinal active ROM among aviators, crews, and signals. It is hypothesized that air-based MOS (aviators and crews) would exhibit limited ROM compared to ground-based MOS (signals). **Design:** Cross-sectional. **Setting:** University-operated, military human performance research laboratory. **Participants:** Thirty-four active-duty male soldiers (28.7±7.4yrs, 177.5±7.4cm, 83.0±15.7kg) were recruited from the 159th Combat Aviation Brigade of the Army 101st Airborne Division: aviators (n=12), crews (n=9), and ground-based signals (n=13). All soldiers were healthy, had no history of surgery, and were cleared for physical training. **Interventions:** A standard digital inclinometer was calibrated and used to measure spinal active ROM in accordance with the American Medical Association guidelines. Cervical spine flexion, extension, and lateral flexion ROM were measured with the inclinometer on the top of head with the subject in a seated position. Cervical right and left rotation ROM were measured in the supine position with the inclinometer on the center of the forehead. Thoracic and lumbar flexion and extension ROM were measured in the sitting and prone position, respectively. Spinal lateral flexion ROM was measured in an upright standing position. Spinal rotation ROM was measured in a standing position with the trunk forward flexed and rotated to the right or left. For thoracic and lumbar ROM, the inclinometer was placed on C7, T12, and L5, and the differences between C7-T12 and T12-L5 were used for thoracic and lumbar ROM, respectively. **Main Outcome Measures:** Degrees of cervical, thoracic, and lumbar spinal rotation in six directions (flexion, extension, right and left lateral flexion, right and left rotation). A one-way ANOVA with the Bonferroni post-hoc test was used for statistical analysis. **Results:** Lumbar extension, right and left lumbar lateral flexion, and left cervical rotation ROM were statistically significant (p>0.05). The post-hoc tests revealed that aviators had limited lumbar extension ROM compared to signals (aviators=37.6°±6.7, signals=50.8°±11.2, p=0.004). Both aviators and crews had limited right and left lumbar lateral flexion ROM than signals (Right: aviators=20.8°±6.7, crews=20.1°±5.7, signals=26.5°±3.5, p=0.013; Left: aviators=22.2°±6.7, crews=21.0°±5.1, signals=29.6°±6.3, p=0.001). Aviators had limited left cervical rotation ROM compared to signals (aviators=84.0°±8.1, signals=92.4°±5.0, p=0.034). **Conclusions:** Aviators and crews have limited spinal ROM compared to ground-based signal soldiers. These ROM limitations may place these MOS groups at greater risk for low back and cervical pathology. Additional studies should focus on

interventions to restore spinal ROM in order to reduce the potential risk of injury. **Word Count:** 450

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The Perception of Load Carriage as a Risk Factor for Injury in U.S. Army Soldiers: 835: June 1 11:00 AM - 11:15 AM

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The prevention of musculoskeletal injury is a principal concern of clinicians who care for military servicemen and the commanders responsible for their well-being. Anecdotal reports indicate that Soldier load carriage may contribute to injury, but epidemiological evidence is lacking.

PURPOSE: To survey Soldiers about the circumstances of their injury and perception of load carriage as a contributor to musculoskeletal injury.

METHODS: Self-reported musculoskeletal injury data were collected on 207 Soldiers of the U.S. Army's 101st Airborne Division (Air Assault). Soldiers were asked to provide a historical account of all injuries and answer specific questions about load carriage. Questions included whether they were carrying load; when the injury occurred; the amount/type of load; the time duration that load was worn prior to the injury; and whether they considered load carriage as a contributor to the injury.

RESULTS: A total of 207 injuries occurred during organized military activities. The average number of injuries reported per Soldier was 1.0 ± 1.3. Fifty-eight Soldiers reported that they were carrying load when one or more of their injuries occurred. Soldiers reported that 77 of the 207 (37.2%) injuries occurred while they were carrying a load; of these load-associated injures, 24.7% (19/77) occurred during deployment. The majority of these injuries (61/77, 79.2%) were to the lower extremity or spine. Soldiers indicated that carrying a load contributed to their injury in 56 of the 77 cases (72.7%). According to the Soldiers, the total weight of their load was 81.5 ± 53.9 pounds (44.5 ± 27.1 % body weight). In 25 of the injuries, load was worn each day on average 1 to 4 hours prior to injury.

CONCLUSIONS: A large proportion of injuries occurred while Soldiers were carrying load with Soldiers indicating that load carriage contributed to injury in a majority of these cases. Although load carriage as a specific risk factor for injury has not been established, it is a possible contributor, and warrants more detailed examination. Special consideration should be given to the prevention of injuries during deployment due to environmental conditions and geography.

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Postural Stability
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Title

Gender Differences in Static and Dynamic Postural Stability of Soldiers of the Army's 101st Airborne Division (Air Assault)

Authors

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Purpose/Hypothesis

Female Soldiers are at increased risk of musculoskeletal injury compared to male counterparts. The identification of gender-specific risk factors for injury or differences between genders would provide evidence for modification of physical training programs. Postural stability (PS) has been identified as a risk factor for musculoskeletal injuries in civilian athletes with few equivalent studies in military populations. The purpose of this study was to examine static and dynamic PS in male and female Soldiers. We hypothesized female Soldiers would have better static PS but decreased dynamic PS compared to male Soldiers.

Number of Subjects

Data were collected on 25 healthy female Soldiers (age 26.4±5.3 years; height 162.1±6.7 cm; weight 63.2±10.3 kg) and 25 male Soldiers (age 26.4±4.9 years; 176.0±7.9 cm; weight 85.5±11.3 kg) matched on age (±2.0 years), demand rating (exact), and years of service (±2.0 years) from the Army's 101st Airborne Division (Air Assault). All subjects were cleared for full active duty.

Materials/Methods

Static postural stability was assessed using single-leg stance (eyes open (EO) and eyes closed (EC)) conditions. Ground reaction force standard deviations (GRFSD) were collected in the anterior-posterior (AP), medial-lateral (ML) and vertical (V) force directions to quantify static postural stability. Dynamic postural stability was assessed using a double-leg jump landing requiring the Soldier to jump forward from a starting point of 40% of their height; jump over a 30cm hurdle; land on a single-leg on a force plate; and stabilize for ten seconds. The dynamic postural stability index (DPSI) was calculated based on ground reaction forces immediately following initial contact (3 seconds). Paired t-tests were used to compare differences between genders. Statistical significance was set at $p<0.05$ *a priori*.

Results

Female Soldiers had significantly better static PS in EO AP GRFSD (F: 2.9±1.7; M: 3.6±1.0; p=0.028), EO ML GRFSD (F: 2.2±0.83; M: 2.8±0.81; p=0.004), EC AP GRFSD (F: 6.9±2.5; M: 10.0±4.4; p=0.005), EC ML GRFSD (F: 4.6±1.6; M: 6.1±2.2; p=0.009), and EC V GRFSD (F: 9.6±5.1; M: 13.6±7.3; p=0.030). There were no differences between genders for dynamic PS variables (p>0.05).

Conclusions
Female Soldiers had better static PS but similar dynamic PS compared to male Soldiers, partially confirming our hypothesis. Civilian athletic research has demonstrated that females have better static PS but decreased dynamic PS compared to males. The lack of differences in dynamic PS may be explained due to matching of the two groups based on age, years of service, and demand rating. The matching of subjects may indicate that they have had similar exposure to dynamic conditions in physical and tactical training.
Clinical Relevance
Female and male Soldiers of the Army's 101st Airborne/Air Assault Division have different static PS. Previous literature has indicated that decreased static PS is a risk factor for knee and ankle injury which would indicate that training should include appropriate activities to improve PS.
Key Words
Postural Stability, Balance, Injury Prevention, Dynamic

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Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part II

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Abstract

Introduction: Physical training for United States military personnel requires a combination of injury prevention and performance optimization to counter unintentional musculoskeletal injuries and maximize warrior capabilities. Determining the most effective activities and tasks to meet these goals requires a systematic, research-based approach that is population specific based on the tasks and demands of the Warrior. **Objective**: The authors have modified the traditional approach to injury prevention to implement a comprehensive injury prevention and performance optimization research program with the 101st Airborne Division (Air Assault) at Fort Campbell, KY. This is second of two companion papers and presents the last three steps of the research model and includes *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*. **Methods**: An 8-week trial was performed to validate the Eagle Tactical Athlete Program (ETAP) to improve modifiable suboptimal characteristics identified in Part I. The experimental group participated in ETAP under the direction of a ETAP Strength and Conditioning Specialist while the control group performed the current physical training at Fort Campbell under the direction of a Physical Training Leader and as governed by FM 21-20 for the 8-week study period. **Results**: Soldiers performing ETAP demonstrated improvements in several tests for strength, flexibility, performance, physiology, and the APFT compared to current physical training performed at Fort Campbell. **Conclusions**: ETAP was proven valid to improve certain suboptimal characteristics within the 8-week trial as compared to the current training performed at Fort Campbell. ETAP has long-term implications and with expected greater improvements when implemented into a Division pre-deployment cycle of 10-12 months which will result in further systemic adaptations for each variable.

Introduction

This paper is the second of two companion papers detailing the systematic and data driven injury prevention and performance optimization training program (Eagle Tactical Athlete Program- ETAP) to reduce the risk of unintentional musculoskeletal injuries and improve physical readiness in Soldiers of the 101st Airborne Division (Air Assault). This six step injury prevention and performance model was developed based on the conventional public health approach to injury prevention and control[1-3] and was modified to include *Task and Demand Analysis*. The first three steps of the model were detailed in Warrior Model for Injury Prevention and Human Performance: Eagle Tactical Athlete Program (ETAP) – Part I and included *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. The current paper describes the last three steps of the model and includes *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*.

At the initiation of this research with 101st Airborne Division (Air Assault), the standard physical training guideline used at Fort Campbell was Field Manual (FM) 21-20, published by the Department of the Army.[4] Although this manual covers the fundamental principles of cardiovascular fitness, body composition, muscular endurance, strength, and flexibility, anecdotal reports suggest daily physical training still emphasizes training for performance on the Army Physical Fitness Test (APFT): push-ups, sit-ups, and two-mile run. This assessment encompasses few of the characteristics critical to achieve optimal physical readiness and performance, or reduce injury risk.[5] Unfortunate consequences of such isolated training increase the risk of certain musculoskeletal injuries.[6]

Several military and civilian based training programs have been developed and/or marketed as training programs specific to U.S. Army Soldiers.[7-9] Common to these programs is the concept of treating the Soldier as a "tactical athlete." Consequently, these physical training programs are similar to strength and conditioning programs developed for athletes at the university and/or professional level, incorporating aerobic and anaerobic components as well as muscular strength, endurance, and agility. While a few programs have been based on predictors of injury and optimal performance,[10] none of the programs were developed based on injury surveillance of military populations in which the program was implemented or the physiologic, musculoskeletal, and biomechanical demands associated with military-specific training and tactical operations. Many of the programs target individual Soldiers rather than units, potentially making it difficult to implement the program on a larger scale.[7-9] Additionally, few studies have designed and validated an intervention program using Soldiers in regular Army combat units, whose training schedule is largely influenced by deployment cycles and their associated preparatory activities. Only a few of these training programs have been evaluated to determine if the risk of injury is reduced while maintaining or improving physical performance, including the APFT.[11] Consistent with the public health approach to injury prevention and control,[1-3] it is imperative to monitor and determine the effectiveness of these training interventions to reduce injury and optimize performance.

The purpose of this paper is to describe the last three steps of the research model- *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program*,. It was hypothesized that performance of ETAP would result in favorable adaptations to laboratory, field, and APFT performance compared to the current training performed at Fort Campbell as governed by FM 21-20.

Design and Validation of Interventions

Methods

Subjects

A sample of 60 male and female Soldiers from the 101st Airborne Division (Air Assault) were recruited from a single Brigade through posted advertisements and information sessions arranged by the investigators. All subjects were cleared for active duty without any injury profile prescribed throughout the study period or within the three months prior to enrollment. Subjects were matched on age, gender, and two-mile run time from their last APFT and then one member of each pair was randomly assigned to either an experimental group- ETAP (N: 30, Age: 24.6 ± 5.2 years, Height: 168.5 ± 24.5cm, Mass: 68.3 ± 3.3kg) or control group- current PT (N: 30, Age: 25.1 ± 5.8 years, Height: 168.5 ± 25.5cm, Mass: 69.1 ± 3.3kg). Human subject protection for the current study was approved by the University of Pittsburgh, Dwight D. Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All tests were conducted at the Human Performance Research Center, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

ETAP Overview

ETAP is a cyclic program which allows for modifications to the individual training cycles according to unit schedules and missions. When implemented, each cycle is separated by one to two weeks of tapered activity to ensure proper recovery and to reduce the risk of overtraining. Each cycle is designed to build upon the previous cycle and varies in intensity and duration. ETAP is designed for implementation with little to no equipment and can be easily executed in garrison or while deployed. Overall volume, intensity, rest, and distance varies across the phases: phase I focuses on general adaptation and introduction to the exercises; phase II focuses on gradual increase in volume; phase III focuses on gradual increase in intensity with less volume, and phase IV focuses on taper prior to the post-test, deployment, or cycle reset. The program consisted of five main workout sessions per week over eight weeks, each with a specific fitness component focus (Table 1). Each workout session began with a dynamic warm-up and finished with a cool-down and static stretching. Each session was dedicated to one of the following training objectives: Day-1) speed, agility, and balance; Day-2) muscular strength; Day-3) interval training; Day-4) power development; and Day-5) endurance training. The total workout duration for each daily physical training session was consistent with the guidelines published in FM 21-20 and as instructed at Fort Campbell.

The Day-1 workout session was designed to improve anaerobic power and capacity (which were identified as suboptimal during *Predictors of Injury and Optimal Performance*) and incorporated speed and agility exercises. Interval training with approximately a 1:3 or 1:2 work to rest ratio was incorporated for anaerobic system enhancement. Activities included shuttle runs, sprints, lateral movement drills, and agility drills. Shuttle runs and sprints used a funnel design, with the volume (total distance) progressing from high (274 meters (m)) to low (27 m) which dictated that the intensity progresses from low to high. Sprint training has been reported to induce neural adaptations, specifically increased nerve conduction velocity and motor-neuron excitability.[12] Agility and lateral movement (line, cone, and ladder) drills progressed from simple patterns with shorter duration, distance, or volume to more complex patterns with longer duration, distance, or volume. Agility drills included line, cone, ladder drills, and advance shuttle and combined skills activities.

The Day-2 workout session was designed to improve muscular strength and muscular endurance, with the focus of increasing total body muscular strength. Strength training consisted primarily of resistance exercises that required no to a minimal amount of equipment and therefore

TABLE 1 **ETAP Design/Overview**

DAY 1: Anaerobic Conditioning Shuttle runs, sprints, lateral movement, and agility Shuttle runs and sprints use a funnel design through an eight week cycle. The longest distance (274 m) will be performed early progressing to the shortest (27 m) distance. The volume (total distance) progresses from high to low which dictates that the intensity must progress accordingly, from relatively low to high. Agility and lateral movement drills will progress from simple patterns and shorter duration or distance to more complex patterns and longer duration or distance.	DAY 2: Resistance I Strength training consist of performing exercises using no equipment to a minimal amount of equipment, that can be executed anywhere. The goal is to increase total body muscular strength. The workouts are balanced for total body development; front/back, left/right, and top/bottom.
DAY3: Aerobic Intervals/Balance drills Aerobic intervals include running distances ranging from 800 – 1200 meters, individual dependent, for time followed by active or passive recovery. Interval run time goals is from 3:30 – 5:00 minutes. The number of aerobic intervals progresses from 3 – 5 depending on group and program length. Interval running recovery duration will progress from a longer to shorter time period, initially a 1:1 work to rest ratio. Static and dynamic balance drills are performed with eyes open and eyes closed. Progression is dependent on group ability.	DAY 4: Resistance II Builds on Day 2, Resistance I workout. Strength training consist of performing exercises using no equipment to a minimal amount of equipment, that can be executed anywhere. Includes basic resistance training exercises along with upper and lower body plyometric exercises. The goal is to improve muscular strength and power.
DAY 5: Aerobic Conditioning Distance runs and foot marches are performed. Runs and foot marches can be executed in formation or in ability groups. The goal is to increase VO_{2max} and foot march efficiency and progresses from shorter to longer distances.	

could be executed anywhere. Equipment employed included the following: Interceptor Body Armor (IBA), body weight, sandbags, partner resistance, resistance tubing, and dumbbells. Exercise intensity, volume and rest were prescribed according to a recommendation by the American College of Sports Medicine[13] and the volume was manipulated throughout the cycle by altering the duration the exercises were performed. The workout session incorporated full body strength training to ensure a well balanced program and exercises were selected specifically to address muscle weaknesses and/or imbalances as identified during *Predictors of Injury and Optimal Performance*. Targeted muscles included hip adductor/abductor, hamstrings, the rotator cuff and trunk rotators.

The Day-3 workout session was designed to improve aerobic capacity through interval runs.[14, 15] The distance for the interval run ranged from 800-1200m, with the interval run lasting between four to five minutes and performed at or near VO_{2max}. Running faster than VO_{2max} pace does not necessarily produce a greater aerobic benefit; therefore, the interval distance was carefully monitored and adjusted individually.[16] Initially subjects were assigned to one of three interval distances based on APFT two-mile run times (≤ 15:00, 1200m; 15:01 - 17:59, 1000 m; ≥ 18:00, 800m). When a subject consistently finished the interval run in less than four minutes or greater than five minutes, then he/she was moved into a longer or shorter distance group, respectively. Prior to the workout, each Soldier was given an individualized goal time to complete the interval runs, based on the average time for his/her interval runs from the previous week. The work to rest ratio was designed to be close to 1:1, but varied by individual due to group size and individual finishing times. Early in the eight-week cycle, the rest time was slightly higher than the work time. As the cycle progressed, the rest time decreased slightly (with a minimum of 4:30 minutes). Also, the cycle began with two to three intervals with five minutes of rest/recovery and gradually progressed to four to five intervals with 4.5 minutes of rest/recovery. Static and dynamic balance drills also were performed at the completion of this workout. Several variation of one leg balance drills with eyes open and eyes closed were also performed.

The Day-4 workout session was designed to improve muscular strength and explosive power. This session built on the main workout session from Day-2. As with Day-2, the volume was manipulated throughout the cycle by altering the time that the exercises were performed. During the first four weeks of the cycle, circuit training which incorporated full body exercises along with upper and lower body plyometric exercises was performed. During weeks five and seven, the IBA was worn during the circuit, with no IBA during weeks six and eight to allow for rest/recovery. Proper landing technique was taught and landing drills executed to decrease ground reaction forces, which were identified in the companion paper as suboptimal. Intensity and volume of plyometric exercises were carefully monitored and introduced according to safety recommendations.[17, 18] Lower body plyometric exercises have been shown to reduce GRF due to a strength increase in the hamstring muscles accompanied by an improvement in the flexion/extension ratio.[19-22] Teaching and utilizing proper landing techniques also reduces the impact forces, therefore decreasing the risk of injury.[23] Training volume for lower body plyometric exercise was limited to 40-60 landings (4-6 exercises) per session and the jump intensity was limited to vertical jumps, tuck jumps, lateral and front-to-back line and cone hops/jumps, jumping rope, five dot drill and small box drills and landings. Upper body plyometric activities included APFT speed pushups, clapping pushups, and a variety of medicine ball exercises.

The Day-5 workout session was designed to improve aerobic endurance. Distance runs and foot marches were performed on alternate weeks. The goal was to increase aerobic capacity (VO_{2max}) and foot march efficiency and therefore progressed from shorter to longer distances. For the foot march, the minimum pace was set at three miles per hour (20 min/mile) as per Fort Campbell standards. The initial distance was three miles and was increased by a half mile each march. Additionally, the load carried was gradually increased as follows: no load, IBA/Advance Combat Helmet (ACH), IBA/ACH with a 6.8 kg rucksack, and IBA/ACH with a 11.4 kg rucksack. Distance runs began with two to three miles at a steady pace and gradually progressed up to six miles.

Experimental Design

A pretest/post test randomized controlled design was used for this study. All subjects reported to the Human Performance Research Center for pre- and post-intervention testing. The experimental group participated in ETAP under the direction of an ETAP Strength and Conditioning Specialist while the control group performed current physical training at Fort Campbell as governed by FM 21-20 for the eight-week study period under the direction of the groups Physical Training Leader. Subjects reported each morning, Monday through Friday, at the regularly scheduled physical training time, for eight weeks. The ETAP Strength and Conditioning Specialist and Physical Training Leader were solely responsible for instructing physical training and were not involved with the data collection procedures.

Table 2

Pre- and Post-Static/Dynamic Balance (Mean ± SD)

	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
A/P EO (NM)	2.5 ± 0.6	2.3 ± 0.5	2.5 ± 0.6	2.5 ± 0.8
M/L EO (NM)	3.0 ± 1.0	2.9 ± 0.8	3.2 ± 0.8	3.4 ± 1.1
V EO (NM)†	4.3 ± 1.7	4.1 ± 1.6	4.5 ± 1.7	4.6 ± 2.2
A/P EC (NM)†	6.7 ± 3.5	5.1 ± 1.5	7.0 ± 3.6	6.2 ± 2.1
M/L EC (NM)†	9.5 ± 3.8	7.8 ± 2.1	10.1 ± 3.7	9.5 ± 3.1
VEC (NM)	14.2 ± 10.1	10.3 ± 4.0	15.2 ± 11.2	12.7 ± 5.6
MLSI (NM)	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01
APSI (NM)	0.15 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	0.15 ± 0.01
VSI (NM)†	0.38 ± 0.04	0.36 ± 0.04	0.38 ± 0.05	0.37 ± 0.05
DPSI (NM)†	0.41 ± 0.04	0.39 ± 0.04	0.41 ± 0.04	0.40 ± 0.05

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Laboratory Testing

The laboratory testing procedures used to evaluate the effectiveness of ETAP to modify biomechanical, musculoskeletal, and physiological characteristics were identical to those described in *Predictors of Injury and Optimal Performance* of Warrior Model for Injury Prevention and Human Performance: Eagle Tactical Athlete Program (ETAP) – Part I. For the sake of brevity and repetitiveness any protocol deviations from the companion paper and related variables are described below.

A low back and hamstring flexibility protocol was assessed with the Novel Products Acuflex® I Sit and Reach Box (Rockton, IL). With shoes removed, the subject sat on the floor with the knees straight and feet flat against the box. The subject placed one hand on top of the other with the fingers aligned and then reached out as far as possible without jerking or bouncing while ensuring the hands stayed in proper position and paused momentarily for measurement. The average of three trials was recorded.

Field Testing

Maximum vertical jump height was determined using the Vertec (Questtek Corp, Northridge, CA). Standing reach was obtained and recorded by having the subject stand directly under the Vertec and extend the dominant arm and hand to gently touch the highest vane possible. Each subject performed a standing countermovement jump for maximum height, reaching the highest vane on the Vertec. Vertical jump was obtained by determining the difference of the maximum jump height and standing reach. A 30-60 second (s) rest was provided between trials. The average of three trials was recorded.

The standing broad jump was measured as the subject performed a countermovement and a two legged forward jump for maximal distance (standing broad jump). Subject's arms were free to move throughout performance of the standing broad jump. Subjects were allotted approximately 30-60 s rest between trials. Distance was measured between the starting position and the most posterior heel-ground contact without the subject falling. The average of three trials was recorded.

The agility task was performed as the subject started in a two point stance straddling the middle cone of three cones, each separated by 4.6m. The subject sprinted (either direction) to the adjacent cone, touched the line with the outside hand and changed direction (ensuring not to pivot all the way around), sprinting past the middle cone to the far cone. The subject touched the line with the outside hand, changed direction, and sprinted past the middle cone, which was the finish line. The time to complete the drill was averaged across three trials. Subjects were allotted approximately 30-60 s rest between trials.

The shuttle run was performed in a straight line between two

Table 3 Pre- and Post-Flexibility (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Active Knee Extension (deg)*#	21.6 ± 8.1	20.7 ± 8.8	24.4 ± 8.6	28.5 ± 9.2
Ankle Plantarflexion (deg)	54.4 ± 7.5	51.5 ± 8.3	55.6 ± 5.7	52.5 ± 5.5
Ankle Dorsiflexion (deg)*†	9.2 ± 6.0	10.7 ± 4.7	10.6 ± 5.0	9.5 ± 4.7
Low Back/Hamstring (cm)*†	17.2 ± 2.7	18.6 ± 2.4	15.6 ± 4.1	15.6 ± 4.0
Torso Rotation (deg)*†#	68.7 ± 11.7	77.6 ± 12.4	72.3 ± 7.7	68.2 ± 7.9

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Table 4 Pre- and Post-Strength (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Knee Flex (%BW)†	119.1 ± 29.3	128.0 ± 29.5	118.1 ± 25.4	122.6 ± 19.5
Knee Ext (%BW)*†#	236.0 ± 48.9	244.1 ± 42.3	243.3 ± 50.6	223.4 ± 31.8
Knee Flex/Ext Ratio	0.5 ± 0.1	0.5 ± 0.1	0.5 ± 0.1	0.6 ± 0.1
Shoulder Int Rot (%BW)	54.0 ± 15.1	53.0 ± 16.0	53.4 ± 12.7	52.8 ± 9.9
Shoulder Ext Rot (%BW)	42.4 ± 9.1	38.1 ± 7.3	42.3 ± 7.7	39.8 ± 6.1
Shoulder ER/IR Rot Ratio	1.3 ± 0.3	1.4 ± 0.4	1.3 ± 0.2	1.3 ± 0.2
Torso Rotation (%BW)*†	128.5 ± 33.5	137.6 ± 27.4	137.7 ± 26.8	136.9 ± 30.5

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Table 5 Pre- and Post-Physiology (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Body Fat (%BF)	19.0 ± 7.5	18.9 ± 7.9	18.7 ± 7.3	19.3 ± 7.1
Anaerobic Power (W/kg)*†#	11.9 ± 2.3	14.0 ± 2.4	11.7 ± 2.2	12.7 ± 2.2
Anaerobic Capacity (W/kg)†#	7.5 ± 1.2	8.1 ± 1.0	7.2 ± 1.3	7.6 ± 1.0

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Table 6 Pre- and Post-Field Tests (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Vertical Jump (cm)*†#	54.4 ± 11.9	56.6 ± 11.7	55.6 ± 10.2	56.6 ± 10.4
Horizontal Jump (cm)†#	194.1 ± 33.3	201.9 ± 32.8	192.0 ± 27.4	197.1 ± 29.7
Pro Agility (s)*†	5.4 ± 0.5	5.3 ± 0.4	5.4 ± 0.5	5.4 ± 0.4
Shuttle Run (s)*†	69.2 ± 6.2	66.8 ± 6.3	71.0 ± 8.0	71.3 ± 8.5

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Table 7 Pre- and Post-APFT (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
Pushup (reps)	51.7 ± 13.0	53.3 ± 9.0	53.6 ± 13.9	54.4 ± 12.3
Situp (reps)*†#	58.9 ± 13.3	68.0 ± 10.0	58.6 ± 8.6	62.5 ± 9.8
2 Mile (min)*†#	16.6 ± 2.4	15.4 ± 2.0	16.6 ± 2.6	16.0 ± 2.0

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

Table 8 Pre- and Post-Biomechanics (Mean ± SD)				
	101st Airborne Division (Air Assault)			
	Exp - Pre	Exp - Post	Control - Pre	Control - Post
HipFlexIC (°)	39.7 ± 11.5	41.6 ± 11.7	40.3 ± 10.0	42.2 ± 9.9
HipAbdIC (°)	-5.1 ± 3.5	-4.3 ± 3.8	-4.4 ± 3.8	-4.6 ± 3.4
KneeFlexIC (°)	24.3 ± 8.2	25.1 ± 7.5	23.4 ± 8.3	24.7 ± 7.7
KneeVVIC (°)	3.2 ± 5.0	2.9 ± 4.8	4.1 ± 6.6	1.5 ± 5.7
KneeFlexMax (°)	89.0 ± 12.0	87.9 ± 10.5	85.4 ± 14.3	86.4 ± 9.7
PeakvGRF (%BW)	209.9 ± 49.0	197.0 ± 48.1	254.7 ± 71.2	232.3 ± 60.6
AnkleFlexIC (°)	-7.1 ± 14.2	-5.4 ± 14.9	-5.9 ± 16.1	-7.2 ± 15.6
AnkleFlexMax (°)	26.2 ± 5.7	25.3 ± 5.0	25.9 ± 5.1	25.2 ± 4.1

*Significant pre/post intervention between group differences ($p < 0.05$)
†Significant pre/post intervention experimental group differences ($p < 0.05$)
#Significant pre/post intervention control group differences ($p < 0.05$)

FIGURE 1

ETAP ICS CURRICULUM

Day 1	
0930 - 0945	Introduction to ETAP ICS
0945 - 1000	Paperwork: Informed Consent
1000 - 1130	ETAP Day 1 Workout
	- Anaerobic intervals
	- Energy pathways
	- Cone drills
1130 - 1300	Lunch break
1300 - 1330	Introduction to ETAP Basic exercise physiology presentation
1330 - 1345	Dynamic warm up: Classroom presentation
1355 - 1405	Static stretching: Classroom presentation
1405 - 1415	Break
1415 - 1425	Dynamic warm up: Practice and corrections in gym
1425 - 1450	Anaerobic conditioning: Classroom presentation
1450 - 1515	Agility, balance, & coordination: Walkthrough/Interactive presenation in gym
1515 - 1530	Agility ladder drills: Practice and setup

Day 2	
0930 - 0945	Performance testng information: Classroom brief
0945 - 0950	Transition to gym for Day 2 workout
0950 - 1120	ETAP Day 2 Workout
	- Full body resistance training day
1120 - 1130	Question and Answer period
1130 - 1300	Lunch break
1330 - 1430	Nutrition for athletes: Classroom presentation
	- Basic nutrition concepts
	- Sports nutrition concepts
	- Weight control information
	- Supplements: Use of and cautions
1430 - 1440	Break
1440 - 1520	Resistance I/Strength Training: Classroom presentation
	- Principles/guidelines and proper techniques
	- Muscle contraction
	- Partner resisted exercise
	- Alternative forms of resistance
	- Alternative forms of workouts
	- Workout considerations
1520 - 1525	Aerobics intervas (Day 3 Preview): Classroom
1525 - 1530	Question and Answer period

Day 3	
0930 - 1100	ETAP Day 3 Workout
	- Aerobic intervals
	- Static balance drills
1100 - 1120	Balance drills discussion: Static and dynamic
1120 - 1130	Question and Answer period
1130 - 1300	Lunch break
1300 - 1400	Aerobic intervals/interval running: Classroom presentation
	- Interval running concepts
	- Energy pathways
	- VO2max and LT concepts/theories
	- LT improvement concepts
	- Measuring intensity: RPE & heartrate
	- Using heartrate monitors and software
	- Field measures of aerobic
1400 - 1410	Discussin & interpreting heartrate graphs
1410 - 1420	Break
1420 - 1510	Partner resisted exercise: Practice in gym
1510 - 1520	Proper squat technique: Discussion and practice
1520 - 1530	Question and Answer period

Day 4	
0930 - 1110	ETAP Day 4 Workout
	- IBA Workout
	- Medicine ball exercises
1110 - 1120	Alternative forms of resistance: Show and tell
1120 - 1130	Question and Answer period
1130 - 1300	Lunch break
1300 - 1320	Landing and IBA Workout: Classroom presentation
1320 - 1325	Discussing & interpreting heartrate graphs
1325 - 1400	Resistance II: Classroom Presentation
1400 - 1410	Break
1410 - 1420	Exercise demonstrations and suggestions from Physical Training observations: in gym
1420 - 1430	Push press: Discussion and demonstration Medicine ball and push press: Practice in gym
1430 - 1500	Functional and agility training: Discussion, demonstration, and practice various forms of:
	- Hops: line and cone
	- Vertical jumps
	- Jump rope intensities
	- Unstable surface training
1500 - 1515	Putting it all together: Classroom presentation
1515 - 1525	Workout cards and DVD: Explanation
1525 - 1530	Course evaluation and distribution of Certificates of Completion

cones, separated by 22.9m and timed for a total completion of 274.3m (six laps). Subjects were instructed to touch the end lines with their hands prior to change in direction. One trial was completed and recorded.

The APFT was conducted by a non-commissioned officer in charge responsible for administering and scoring the individual components of the APFT. Subjects were allotted two minutes to perform maximum repetitions of sit-ups, two minutes to perform maximum repetitions of push-ups, and timed two mile run according to APFT standards as outlined in FM 21-20. A 10-minute rest period was allowed between each testing component.

Statistical Analysis

Data were examined to assess the assumptions of normality and of equality of variance. These assumptions were not met in the case of some variables. Descriptive statistics (measures of central tendency and measures of dispersion) were estimated for all variables. The absolute differences from pre- and post-testing for the experimental and control group were calculated for all variables. Both parametric tests for normally distributed data and non-parametric tests were used to compare absolute differences from baseline between the experimental and the control group. The results of the non-parametric test (Wilcoxon rank-sum test) agreed with the results of the corresponding parametric test (independent samples t-test) with respect to direction of change and significance of the results in the majority of the variables and reported as parametric analysis. Statistical significance was set at $p < 0.05$ for all variables.

Results

The 8-week trial was comprised of 35 training sessions and accounted for five days of no scheduled activities according to the Fort Campbell operating schedule. The average attendance for the experimental group was 89% (31 sessions) with a range of 54-100%. A minimum attendance of 80% of the training sessions was achieved by 80% of the subjects in the experimental group. The average attendance for the control group was 94% (33 sessions) with a range of 71-100%. A minimum attendance of 80% of the training session was achieved by 96% of the subjects in the control group.

Flexibility/range of motion, strength, and balance data are presented in Tables 2- 4. Compared to the control group, the experimental group demonstrated improved active knee extension ($p < 0.001$), ankle dorsiflexion ($p = 0.018$), lumbar/hamstring flexibility ($p < 0.001$), and torso rotation flexibility ($p < 0.001$). No significant group differences were demonstrated in ankle plantar flexion ($p > 0.05$). Compared to the control group, the experimental group demonstrated significant improvements in knee extension strength ($p < 0.001$) and torso rotation strength ($p = 0.036$). No significant group differences were demonstrated in knee flexion or shoulder strength ($p > 0.05$). No significant group differences were demonstrated in eyes open or eyes closed balance ($p > 0.05$).

Physiological, field assessment, and APFT data are presented in Tables 5- 7. No significant group differences were demonstrated for percent body fat ($p > 0.05$). Compared to the control group, the experimental group demonstrated significant improvements in anaerobic power ($p = 0.019$). Compared to the control group, the experimental group demonstrated significant improvements in the sit-up ($p = 0.022$) and two mile timed run ($p = 0.039$) portions of the APFT, vertical jump ($p = 0.042$), agility ($p = 0.019$), and 300 yard shuttle run ($p = 0.005$).

Biomechanical data are presented in Table 8. No significant differences were demonstrated for the biomechanical variables ($p > 0.05$).

Discussion

The purpose of this paper was to detail the last three steps of the injury prevention and performance optimization model: *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program.* The Eagle Tactical Athlete Program (ETAP) is a comprehensive physical training program for performance optimization and injury mitigation and was based on the tasks and demands of the 101st Airborne Division (Air Assault) Soldiers. It was demonstrated to induce favorable adaptations to a significant number of modifiable characteristics following eight weeks of training as indicated by improvements in strength, flexibility, balance, power, field tests, and APFT. Although several variables did not demonstrate improvements, the authors acknowledge limited exposure with an 8-week program may have contributed to such results. The program duration will be accounted for when periodized to meet the pre-deployment training cycle of 10-12 months. The effectiveness of ETAP to reduce the risk of unintentional musculoskeletal injuries and optimize physical readiness and performance in Soldiers of the 101st Airborne will be assessed over the next year.

Flexibility/range of motion of the hamstring, calf, and torso improved in the experimental group relative to the control group. The results indicate that dynamic stretching with warm-up and static stretching with cool-down as incorporated with ETAP are effective ways to improve flexibility compared to static stretching with warm-up typically seen in the traditional PT. Improvements in flexibility and range of motion may be important in decreasing the risk of musculoskeletal injuries. Hartig and Henderson[24] reported that hamstring flexibility improved in military infantry basic trainees who participated in a stretching intervention and that these trainees also sustained significantly fewer lower extremity overuse than the controls during a 13-week infantry basic training course. It has also been reported that individuals with less hamstring flexibility, measured using a variety of techniques, are significantly more likely to develop hamstring and quadriceps muscle injuries, low back pain, and patellar tendinitis.[25-27] Decreased flexibility of the gastroc-soleus complex (either alone or in conjunction with other variables) has also been identified in increasing the risk of patellofemoral pain syndrome, achilles tendinitis, ankle sprains, and medial tibial stress syndrome.[28-31]

Knee extension, knee flexion, and torso rotation strength improved in the experimental group relative to the control group. Lower levels of strength may be associated with an increased risk of injury or may be a residual effect from a previous injury. In a prospective study of Australian footballers, Orchard et al. reported that hamstring injury was significantly associated with hamstring weakness as measured by peak torque at 60°/sec.[32] Decreased hamstring strength has also been identified in female athletes who subsequently sustained an injury to the anterior cruciate ligament as compared to male matched controls.[33] Individuals with a history of low back pain demonstrate significantly lower trunk strength than controls.[34] As a general guideline for resistance training, the intensity of 70-80% of one repetition maximum for eight to twelve repetitions and three sets for two to three times a week is recommended for novice athletes.[35] The volume and intensity utilized in ETAP were similar to these recommendations. No significant improvements were seen in shoulder strength, which may be the result of an increased focus of lower body strength and endurance.

Single-leg balance with eyes closed was improved in the experimental group; however, no significant differences with eyes open or group differences were demonstrated. Several studies analyzed biomechanical and neuromuscular characteristics after neuromuscular training (typically a combination of plyometric, resistance, balance, perturbation, and agility training) and reported increases in balance performance.[21, 36, 37] Myer et al.,[21] included several dynamic balance exercises on an unstable disc three times a week for seven weeks. The current study incorporated balance exercises once per week and the balance exercises were performed on a stable surface, which was sufficient to improve single-leg balance with the eyes closed. It is possible the lack of significant group differences in the current study may be multifactorial such that both the low frequency and intensity/difficulty of balance exercises were not sufficient to induce large enough changes. In addition, balance, particularly with the eyes open, may be positively impacted by other training modalities (e.g., squats, lunges, ruck marches on an uneven surface) to which both groups may have been exposed.

Neither group demonstrated a significant change in body weight nor percent body fat. Although exercise training increases energy expenditure which may contribute to a negative energy balance and thus body weight loss, numerous studies have found that exercise alone results in little if any weight loss[38-40] This is explained in part by the fact that moderate exercise does not create a large enough energy gap to promote body weight loss.[38] ETAP training was intended to induce adaptations to promote aerobic fitness, anaerobic power and capacity, muscular strength, flexibility, and balance, not necessarily to promote body weight loss. Also, none of the Soldiers in the current study received any instructions on modifying their diets. There is little evidence to suggest exercise alone will provide the amount of weight loss similar to that generally achieved by diet restriction.[38, 39] Research has shown that higher levels of exercise and or the addition of energy restriction may be necessary to promote significant body weight and fat loss[39, 41-43]

Relative to the control group, the experimental group demonstrated significant improvements in anaerobic power. During the Wingate test, higher anaerobic power is a function of pedaling speed and torque. It is possible that this improvement in anaerobic power resulted from training effects induced by the sprinting and agility exercises along with resistance exercises performed during ETAP. The experimental group also demonstrated a significant improvement in anaerobic capacity. These improvements may be the result of interval training and the varied intensity of exercise that was provided during ETAP. Significant improvements in agility and the shuttle run were seen in the experimental group as compared to the control group. These adaptations may be the result of the targeted training provided by ETAP. Many athletic movements and tactical maneuvers rely on anaerobic capacity, power, and a combination of agility-type activities.

In terms of the APFT, the cardinal assessment of fitness in the U.S. Army, the experimental group demonstrated significant improvements in the sit-ups and two mile run relative to the control group. The key finding is that ETAP was able to improve two mile run performance without the high running mileage typical seen with Army PT. The results of the current study, when combined with previous epidemiological studies, indicate that it may be possible to reduce the incidence of injury during military training by reducing running mileage without compromising fitness as assessed by the APFT.[44-46]

No significant improvements in any of the biomechanical characteristics were seen in either group. Previous research that investigated the effect of plyometric programs coupled with resistance programs on lower extremity kinematics has produced conflicting results.[21, 43, 48] Myer et al.,[21] reported an increase in hip abduction angle and no changes in knee valgus/varus angle after seven weeks of a plyometric training program and a balance training program. Lephart et al.,[47] reported an increase in knee flexion and hip flexion following an eight-week program that incorporated resistance, balance, and plyometric training. However, no changes in knee valgus/varus and hip abduction angle were observed. Similarly, Chappell et al.,[48] reported an increase in knee flexion angle and no changes in knee valgus/varus and hip abduction angle after six weeks of neuromuscular training. The validation trial of ETAP was based on an 8-week trial and may not have been a sufficient duration to induce biomechanical adaptations during landing activities as ETAP was designed to improve multiple areas throughout the 8-week trial with the understanding of eventual expansion to a pre-deployment cycle.

There are several limitations to the current study. Although the U.S. Army provides field manuals to guide physical training, physical training is administered at the discretion of the unit leader and can vary extensively within a Division. It was requested of the Physical Training Leader that he instruct physical training for the control group as he would if not participating in the trial. Within the Division this could suggest an overlap in training or similar training being performed relative to the experimental group. In addition, many military personnel train on an individual basis to supplement unit PT but were instructed to restrict outside exercise/training beyond morning physical training while enrolled in the 8-week trial. This was not monitored in the current study, however if performed, this training may have enhanced the results of the control group to improve certain characteristics. Soldiers performing ETAP demonstrated significant improvements in several variables that are vital to optimizing physical readiness and performance and potentially reducing the risk of unintentional musculoskeletal injuries. Implementation of ETAP into the Division should have long-term implications to improve physical readiness of the Soldier when periodized across a 10-12 month pre-deployment cycle when sufficient exposure and duration is achieved for all components of physical training to allow for complete adaptation of the suboptimal characteristics.

The Department of the Army has recognized the need for updated physical training guidelines to better address more aspects of physical fitness in order to improve performance and physical readiness while reducing the risk of injury. The Army replaced FM 21-20, which was the guideline that governed physical training being performed at Fort Campbell at the time of this study, with TC 3-22.20, *Army Physical Readiness Training*.[10] Epidemiological studies have demonstrated the effectiveness of PRT to reduce injuries while maintaining or improving APFT during Basic Combat Training (BCT) and Advanced Individual Training (AIT).[44-46]

Future studies and programs should incorporate more upper body training. No changes in upper body strength were demonstrated in either group. However, previous studies have reported a high incidence of shoulder instability, dislocation, and rotator cuff tears in the military population[49-51] and that reduced shoulder internal and external rotation peak torque is typically seen with shoulder impingement syndrome and instability.[52-54] Future studies should also monitor and attempt to further control for physical training performed outside of daily Army PT. Finally, it is important to incorporate meal planning and nutritional educational sessions in any injury prevention and performance optimization program if body composition changes are desired.

The final two steps of the public health approach to injury prevention and control: *Program Integration and Implementation* and *Monitor and Determine the Effectiveness of the Program* are currently ongoing and will be completed over the next year. *Program Integration and Implementation* includes the ETAP Instructor Certification School (ICS). ICS is a four-day program designed to teach physical training leaders (NCOs) how to implement and effectively instruct ETAP at the unit level and is based on the Army concept of "train-the-trainer". The final step: *Monitor and Determine the Effectiveness of the Program* will test the effectiveness of ETAP to mitigate musculoskeletal injuries and optimize physical readiness and performance. A parallel approach has been adopted to include injury surveillance both during garrison and deployment and prospective interval testing of laboratory, performance, and APFT variables.

To date, 952 Soldiers have participated in ICS. Soldiers enrolling in ICS are non-commissioned officers (NCO) who regularly instruct morning physical training. Part of each graduate's responsibility is to teach ETAP to other Soldiers who are unable to attend ICS and instruct at the unit level. Two NCOs (a senior and junior NCO) per platoon participated. To recruit an equal number of Soldiers from each Brigade and accelerate Division-wide implementation, six to eight ICS sessions (weeks) were scheduled for each Brigade, with the unit assignment based on the Brigade's and Division's pre-deployment training cycle. The goals of ICS include: 1) experience and understand a comprehensive physical fitness program, 2) understand the components and underlying principles of ETAP to effectively adapt it to individual or unit situations, and 3) develop a working understanding of how to implement ETAP with little to no equipment to ensure that the program is deployable. Daily activities over the four-day course allow for participants to achieve these goals through a multifaceted learning approach. The Soldiers were familiarized with the exercises and the program through participation in ETAP training sessions; interactive sessions including traditional lectures and presentations as well as open discussion to ensure proper understanding of the theory behind the program. Proper technique, progressions, and corrections for the exercises, and alternative exercises and/or training that can be employed while still accomplishing the same goals are covered during "hands on" practice sessions to implement and instruct ETAP. A course outline for ICS is summarized in Table 9. Day 1 covered basic exercise physiology, warm-up/cool-down, stretching, anaerobic conditioning, and agility exercises. Day 2 covered nutrition and resistance exercises. Day 3 covered aerobic interval workouts, balance exercises, partner resistance exercises, and proper lifting techniques. Day 4 covered plyometric exercises, IBA workouts, medicine ball exercises, landing techniques, and PT program design. At the completion of ICS, students received the eight week ETAP workout cards along with the corresponding DVD. The DVD contains all of the lecture slides, a written description and videos of all exercises performed, exercise progression guidelines, perceived exertion and heart rate guidelines as well as information to develop alternative ETAP exercises given the deployment environment. The validated 8-week ETAP program has been extended according to each Brigade's pre-deployment training schedule with repeated cycles of increasing intensity. The training cycles contain the same principles by which the 8-week model was developed, but modified the progression of each training modality. The weekly training format is identical with individual days dedicated to different components of fitness, yet allowing for combat focus training. Based on ICS enrollment, 40 Soldiers per platoon, and an instructor to Soldier ratio of 2:40 or 1:20 per platoon, approximately 19,500 Soldiers have been exposed to ETAP at the unit level. This ratio allows for adequate supervision of Soldiers performing ETAP, ensuring that proper technique and progressions are maintained. In addition, quality control audits are conducted by personnel from the University of Pittsburgh, ensuring proper delivery of ETAP by the NCOs to their respective units and allowing for implementation-related questions to be answered and assessment of exercise performance/technique of the Soldiers at the unit level.

To date, 1478 out of a projected 2000 Soldiers have been enrolled in step six, *Monitor and Determine the Effectiveness of the Program*. Soldiers from a representative Brigade performing ETAP are participating in this aim as the experimental group while Soldiers from a separate Brigade which performs comparable tactical operations and is deployed to a similar location/environment are serving as the control group. To participate, Soldiers must spend a minimum of six months at garrison and 12 months deployed during participation. History of injuries prior to the study start date will be used to compare the frequency of injuries at baseline between the ETAP and regular Army PT groups. The proportion of subjects with unintentional injury will be compared between the ETAP group and the regular Army PT group at the end of 18 months of follow up, by Chi-square tests. A Kaplan-Meier survival analysis will be used to compare time to injury between the two groups. A Cox regression will be used to adjust for variables such as gender, age, number of months of exposure to the ETAP, years of service, and deployment status.

Summary

The purpose of this paper was to describe the last three steps of the injury prevention and control model: *Design and Validation of the Interventions, Program Integration and Implementation, and Monitor and Determine the Effectiveness of the Program* as studied with the 101st Airborne Division (Air Assault). ETAP is a research-based, comprehensive program developed specifically for the 101st Airborne Division (Air Assault) based on inherent injury epidemiology, task and demand analyses, identification of suboptimal physical and physiological characteristics compared to an athletic benchmark, and previously established injury risk factors.

Although it has been demonstrated that ETAP can positively impact physical readiness in a controlled trial, prospective injury surveillance must occur to properly and accurately assess the effectiveness of ETAP to reduce the risk of unintentional musculoskeletal injuries in Soldiers performing ETAP. Additionally the prospective analysis of performance is necessary to determine the effectiveness of ETAP to optimize physical readiness when delivered by the Soldiers of the 101st Airborne Division (Air Assault). The effectiveness of ETAP to be implemented into the Division and resultant mitigation of unintentional musculoskeletal injuries and performance optimization is ongoing and will be completed over the next year.

The application of the public health model of injury prevention and control is an effective tool to scientifically develop and implement injury prevention and performance optimization programs for the tactical athlete, regardless of tactical demands. The research model described for the development of ETAP and 101st Airborne Division (Air Assault) is adaptable to culturally-specific units and driven by the task and demand analysis by which the entire injury prevention and performance research model can be implemented within different Special Operations Forces units.

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Air Assault Soldiers Demonstrate More Dangerous Landing Biomechanics When Visual Input Is Removed

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ABSTRACT Soldiers are subjected to increased risk of musculoskeletal injuries in night operations because of limited visual input. The purpose of this study was to determine the effect of vision removal on lower extremity kinematics and vertical ground reaction forces during two-legged drop landings. The researchers tested 139 Air Assault Soldiers performing a landing task with and without vision. Removing visual input resulted in increased hip abduction at initial contact, decreased maximum knee flexion, and increased maximum vertical ground reaction force. Without vision, the timing of maximum ankle dorsiflexion for the left leg was earlier than the right leg. The observed biomechanical changes may be related to the increased risk of injury in night operations. Proper night landing techniques and supplemental training should be integrated into Soldiers' training to induce musculoskeletal and biomechanical adaptations to compensate for limited vision.

INTRODUCTION

Landing is a task widely performed in Soldiers' physical and tactical training as well as tactical operations. Examples include exiting a vehicle (from a height), traversing a ditch, and climbing over an obstacle. Landing, even from low heights, typically induces high ground reaction forces (GRFs), which are transferred up of the kinetic chain of the lower extremities[1] and have been linked to musculoskeletal injuries in the lower body.[2] Noncontact knee injuries have been one of the most popular areas of research in sports medicine. Numerous studies have been attempted to identify risk factors and biomechanical characteristics of such injuries.[2–8] The knee has been reported as the most frequently injured body part, and accounted for 10 to 34% of all musculoskeletal injuries among different military groups, from Army Infantry to Naval Special Warfare trainees.[9] The frequency of ankle injury in military may be comparable or only secondary to the knee with 11 to 24% of all musculoskeletal injuries occurred at the ankle.[9] Lephart et al[5] suspected that ankle kinematics may have effects on the GRFs during landing. In simulated parachute landing, subjects who landed flat-footed demonstrated greater GRFs than those who landed with the ball of the foot at initial ground contact.[10]

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Soldiers can be viewed as tactical athletes. Unlike typical civilian athletes, Soldiers commonly perform their tasks with heavy equipment in challenging environments. Soldiers may need to perform tactical operations at nighttime for stealth and security purposes. Although darkness makes a Soldier harder to be detected by enemies, it also decreases or deprives their use of visual input when interacting with the environment. Even with facilitating equipment such as night vision goggles, the Soldier's visual input is still limited as compared to daytime. With limited vision, the vestibular system and the somatosensory system must assume greater demands to maintain Soldier's postural stability. It is questionable whether sufficient adaptations on these two systems have been induced via the Soldier's physical and tactical training.

In the military, most research examining the effect of night operation on injuries have focused on parachuting, during which 61 to 84% of injuries occurred at the moment of landing.[11,12] The relative risk of injury was reported between 1.94 and 3.13 at night, compared with daytime parachuting.[11,13] According to a review by Knapik et al[14], similar elevated risks of injury during night parachuting existed in airborne Soldiers of other countries: 2.4 in Israel, 4.1 in Belgium, and between 1.3 and 41.2 in United Kingdom. It is believed that limited visibility of the landing surface and perception of distance and depth contributed to the higher risk of injury.[14] Such mechanisms should apply to any general landing task with impaired vision. Some researchers have evaluated the landing biomechanics with the removal of visual input with inconclusive results.[15–18] Santello et al[16] found decreased maximum knee flexion and increased vertical ground reaction force (VGRF) without vision, whereas Liebermann and Goodman[15,18] found unchanged or decreased VGRF when blindfolded. Nevertheless, none of these studies involved military population. Unlike the general population, Soldiers have been trained for night operation; such training may induce certain adaptations. By observing Soldiers' night training in a qualitative task analysis, we determined that landing from a jump under low light conditions may be associated with increased risk of lower extremity injury.[19] It is unclear how the biomechanical variables change quantitatively in Soldiers when landing without vision and whether these potential changes would suggest increased risk of lower body injury.

Therefore, the purpose of this study was to investigate how the removal of visual input would affect the lower body kinematics and kinetics of Soldiers performing a landing task. We hypothesized that the removal of visual input would alter landing mechanics and increase GRFs.

METHODS

Subjects

A total of 139 male 101st Airborne Division (Air Assault) Soldiers (age: 28.5 ± 7.1 years, body height: 1.77 ± 0.08 m, body mass: 83.3 ± 13.5 kg) voluntarily participated in this study. Eligible subjects were 18- to 55-year-old males cleared for participation in daily physical and training activities. Exclusion criteria included history of concussion or mild head injury in the previous year, lower extremity or back musculoskeletal pathology that could affect the ability to perform the tests within this study in the past 3 months, history of lower extremity musculoskeletal surgery, or history of neurological or balance disorders. Informed consent was obtained before performance of any testing procedures. The current study was approved by University's Institutional Review Board, Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All the tests were conducted at our Research Center for Injury Prevention and Human Performance, Fort Campbell, Kentucky.

Instrumentation

Six high-speed cameras (Vicon, Centennial, Colorado) operating at 200 Hz and two force plates (Kistler, Amherst, New York) operating at 1200 Hz were used to capture the kinematic and GRF data, respectively. The equipment was synchronized using Vicon Nexus software.

Procedures

Sixteen reflective markers were placed on subject's anatomical landmarks, including the anterior superior iliac spines, posterior superior iliac spines, lateral thighs, lateral knees, lateral shanks, lateral malleoli, calcanei, and second metatarsals. Subjects' anthropometric parameters were measured using an anthropometer (Lafayette Instrument, Lafayette, Indiana). A static trial was captured for each subject at the anatomical position and served as the baseline for joint angle calculations.

The subjects were then asked to perform two-legged drop landings from a 50-cm platform under two conditions: with visual input (WV) and no visual input (NV). For the NV condition, visual input was removed by using a blindfold (Figs. 1 and 2). In true training or combat environments, Soldiers may drop from higher heights such as the deck of an High

FIGURE 1. Drop landing WV.

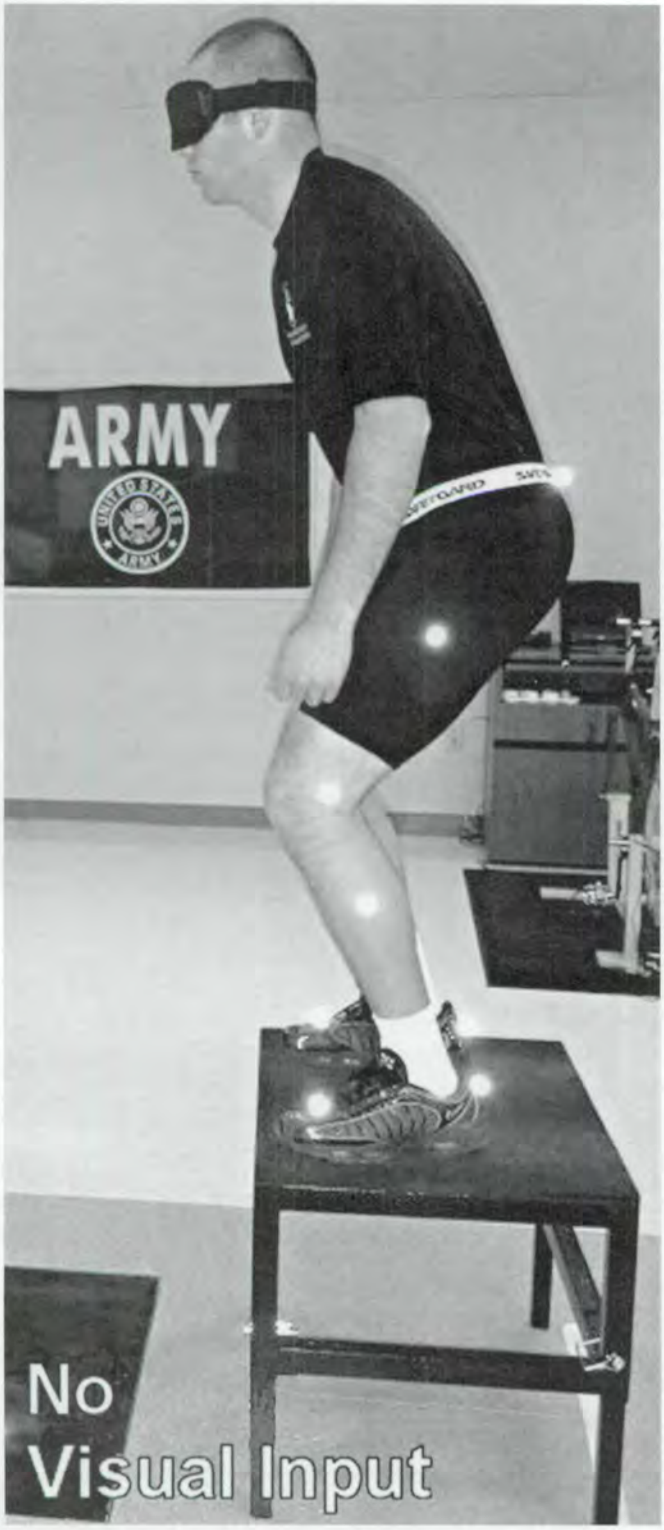

FIGURE 2. Drop landing NV.

Mobility Multipurpose Wheeled Vehicle (HMMWV) (84 cm) or an UH-60 Black Hawk Helicopter (115 cm). In our pilot study, raising the platform height from 50 to 100 cm resulted in an increased VGRF of 95.5% body weight (BW). Because of safety concerns related to the large increase in VGRF, the 50-cm platform height was chosen as this height is comparable to the median platform heights used in previous studies investigating the effects of vision removal.[15–18] The subjects were instructed to stand near the edge of the platform, drop off, land on both feet on the two force plates, and remain standing for 2 seconds after landing. The subjects were given at least three practice trials for each condition. Trials in which the subjects failed to regain balance or touched the ground off the force plates were rejected and replaced. Three successful trials were collected for each condition.

Data Reduction

Vicon Nexus software was used to reconstruct three-dimensional trajectories of the reflective markers. The trajectories were further smoothed with a general cross-validation Woltring filter.[20] The trajectories of the hip, knee, and ankle joint centers were estimated based on the marker locations and anthropometric parameters, according to Vicon's Plug-in Gait model (Vicon). The accuracy and validity of the model have been established.[21–23] The initial contact of each foot during landing was defined as the first sample during which VGRFs exceeded 5% of the subject's BW. The dependent variables included bilateral hip flexion, hip abduction, knee flexion, knee varus, and ankle flexion at initial contact and maximum values for hip flexion, knee flexion, ankle flexion, and VGRFs and the time elapsed from initial contact to these maximum values.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 15; SPSS, Chicago, Illinois). For each condition, dependent *t*-tests were applied to detect both bilateral difference and between-condition differences for each variable. Statistical significance was set at $p < 0.05$.

RESULTS

Results are presented in Table I. Between-condition differences were detected in six variables. Under the NV condition, increased hip abduction angle and increased knee flexion angle at initial contact, decreased maximum knee flexion angle, greater maximum VGRF, decreased time to maximum ankle dorsiflexion, and prolonged time to maximum VGRF were detected in one or both legs.

Four variables showed significant bilateral differences. Hip flexion at initial contact, maximum knee flexion, and maximum VGRF were different bilaterally in both conditions, whereas time to maximum ankle dorsiflexion was different bilaterally only under the NV condition.

DISCUSSION

Landing is a common task performed during military training and tactical operations such as exiting a vehicle from height and traversing uneven terrain or obstacles. When necessary, such tasks are performed at night reducing or eliminating

TABLE I. Between-Condition and Bilateral Comparisons of Joint Angles, VGRFs, and Timings

	Left Leg (Mean ± SD)		Between Condition Comparison (*p*-value)	Right Leg (Mean ± SD)		Between Condition Comparison (*p*-value)	Bilateral Comparison (*p*-value)	
	WV	NV		WV	NV		WV	NV
Initial Contact								
Hip Flexion (°)	22.8 ± 7.0	22.6 ± 7.9	0.492	21.4 ± 6.8	21.2 ± 8.0	0.654	**<0.001**	**<0.001**
Hip Abduction (°)	4.0 ± 3.3	4.6 ± 3.6	**0.002**	3.7 ± 3.3	4.2 ± 3.2	**0.003**	0.412	0.361
Knee Flexion (°)	20.0 ± 6.0	20.0 ± 5.7	0.775	18.1 ± 6.2	18.7 ± 5.8	**0.046**	**<0.001**	**0.004**
Knee Varus (°)	3.4 ± 5.7	3.3 ± 5.7	0.597	3.7 ± 5.1	3.8 ± 4.9	0.871	0.500	0.353
Ankle Plantar Flexion (°)	19.8 ± 9.0	20.0 ± 7.7	0.641	19.3 ± 7.9	19.3 ± 7.5	0.725	0.273	0.142
Maximum Values								
Knee Flexion (°)	89.7 ± 19.4	85.8 ± 19.4	**<0.001**	88.6 ± 19.3	85.4 ± 19.5	**<0.001**	0.116	0.529
Ankle Dorsiflexion (°)	26.9 ± 8.0	26.4 ± 6.3	0.439	27.0 ± 7.2	26.6 ± 6.3	0.336	0.904	0.761
VGRF (%BW)	341.9 ± 96.4	359.9 ± 89.4	**<0.001**	376.1 ± 96.7	384.1 ± 88.2	0.085	**<0.001**	**<0.001**
Time to Maximum Values								
Knee Flexion (ms)	240 ± 115	236 ± 113	0.618	234 ± 81	238 ± 120	0.600	0.346	0.807
Ankle Dorsiflexion (ms)	224 ± 79	212 ± 79	**0.017**	224 ± 70	224 ± 88	0.994	0.904	**0.002**
VGRF (ms)	38 ± 13	40 ± 11	**0.012**	39 ± 16	40 ± 8	0.809	0.346	0.716

The bolded values indicate the significant difference of p <0.05.

visual input.[19] Affected visual input was considered the main reason of increased risk of injury during night parachuting,[14] and the same mechanism should apply to any general landing task under a condition of limited vision. The purpose of this study was to investigate how the removal of visual input would affect the lower body kinematics and kinetics of Soldiers performing a landing task using the biomechanical model developed previously.[5–8] The Soldiers in the current study landed with greater bilateral hip abduction angles at initial contact and lower bilateral maximum knee flexion angles when visual input was removed. Additionally, greater knee flexion angle at initial contact for the right leg, greater maximum VGRF for the left leg, greater time lag to maximum ankle dorsiflexion for the left leg, and greater time lag elapsed to maximum VGRF for the left leg were identified when the Soldiers were blindfolded. The observed biomechanical changes may be associated with increased risk of lower body musculoskeletal injuries.

Under the NV condition, Soldiers demonstrated greater hip abduction angles bilaterally. Without a significant difference in the knee varus angle, the greater hip abduction was likely a strategy to expand the base of support in the medial–lateral direction. If the center of mass falls outside of such area, posture is unstable and the risk of fall increases. Therefore, expanding the base of support reduces the risk of fall and is beneficial for maintaining postural stability. Without visual input, it may be possible that Soldiers attempt to drop and land more cautiously, resulting in unconscious increased abduction of the hips thereby widening the base of support. A post hoc analysis was performed and demonstrated greater distance between the ankle joint centers in the medial–lateral direction ($p < 0.001$). Although the base of support between the feet increased by 3.5%, it cannot be determined if such increase had any clinical significance on posture stability.

The VGRF induced by landing impact are transferred up through the ankles, knees, and hips, and require significant eccentric muscle contraction for stabilization and suppression of forces. The VGRF creates external dorsiflexion torque at the ankles and external flexion torques at the knees and hips. The ankle plantar flexors, knee extensors, and hip extensors contract eccentrically to resist the external torques, maintaining the stability of the lower extremity. At the knee joint, the contraction of the quadriceps creates an anterior shear force at the proximal tibia, placing stress at the anterior crucial ligament (ACL).[24] Increased tibial anterior shear force is related to increased knee extension torque.[8] Therefore, reducing VGRF is considered essential for preventing noncontact ACL injuries. Previous work demonstrated that increased ankle plantar flexion angle at initial contact was related to decreased VGRF.[10] In addition, increasing knee flexion angle at initial contact and allowing greater knee flexion throughout the landing are surmised to reduce VGRF.[25,26] In the current study, no significant difference was found between conditions in ankle plantar flexion at initial contact. However, the maximum knee flexion angles were smaller when visual input was not available. That is, Soldiers flexed their knees less throughout the landing under the NV condition, similar to that reported by Santello et al.[16] The current result suggests that removing the visual input may reduce Soldiers' VGRF dissipation. The mechanism leading to this decreased maximum knee flexion is unclear. It may be a cautious move as people tend to reduce the range of movement and move more carefully in the dark. With decreased knee flexion, the center of mass of the body is maintained higher with less vertical fluctuation. The decreased knee flexion may suggest increased joint stiffness, attributed to increased stiffness of muscles surrounding the knee.[27] Increased muscle stiffness is because of increased muscle activation level, indicating the muscles are preloaded and ready to contract.[27] Both the less-perturbated center of mass and increased muscle stiffness may help Soldiers to be more reactive to unexpected events and ready for the next move during tactical operations.

With decreased maximum knee flexion angles, one may expect to see greater VGRF under the NV condition. However, maximum VGRF increased significantly only for the left leg, with an 18% BW average increase. Recent computer model simulation demonstrated that a 12% BW increase in VGRF resulted in a 9% BW increase in ACL force.[28] The mechanism behind such an asymmetric change in VGRF is unclear. Bilateral comparisons have not been addressed in previous studies investigating visual input during drop landing because only unilateral data were collected.[15–18] Although the two-legged drop landing task is instructed to be symmetrical activity, asymmetric kinematic and force patterns were found in the current study. For both the WV and NV conditions, the hips and knees were more extended resulting in a straightened right leg. A straightened right leg suggests less energy dissipation following the impact. In addition, the right foot may contact the ground earlier, and therefore assumes greater proportion of load at the initial stage of landing when the left foot has not contacted the ground yet. To verify, a post hoc analysis was performed and found the right foot did contact the ground earlier (6 ms, $p = 0.004$ for WV and 5 ms, $p = 0.015$ for NV). These kinematic asymmetries may partially explain the significantly greater VGRF at the right leg for both the WV and NV conditions. The significant increase in the left leg VGRF under the NV condition suggested decreased bilateral difference in VGRF with vision removed. This raised an interesting question that whether Soldiers dropped in a more symmetric manner without vision. The right knee flexion at initial contact increased significantly when visual input was removed, although the angle was still significantly smaller than the left knee. By flexing the knees more symmetrically, the distribution of impact might be more balanced across the two legs, and the VGRF might be more comparable between each leg, as the Soldiers demonstrated under the NV condition.

In the current study, no bilateral difference or between-condition differences were found in ankle plantar flexion angles at initial contact or maximum ankle dorsiflexion angles. However, WV removed, the time elapse from initial contact to maximum ankle dorsiflexion was shorter for the left leg than the right leg. In addition, this elapsed time for the left leg was shorter under the NV condition. Decreased time elapsed indicates shorter time the ankle joint had for dissipating the VGRF through dorsiflexion. As a result, the loading rate of forces applied on the ankle joint may increase, affecting postural stability and increasing the risk of damage in surrounding tissues. The shorter time reaching maximum dorsiflexion at the left ankle may indicate less eccentric performance of the plantar flexors, limiting the capacity of energy absorption. This may also partially explain the significant increase in the left leg VGRF. However, with the ankle angles unchanged, the current evidence is not sufficient to support that the removal of vision is associated with increased risk of ankle injury.

In summary, the current results suggested some potential mechanisms that theoretically could contribute to the higher risk of injury during night operations in the U.S. Army.[11,13] Without vision, decreased maximum knee flexion was identified, which was potentially because of increased muscle stiffness surrounding the knee joint. Although the increased knee joint stiffness may be protective and can contribute to knee joint stability, it also reduces the knee's capacity of force dissipation. Increased VGRF places greater risk of traumatic joint injuries such as strain, sprain, or ligament rupture. Eccentric muscle activity at the left ankle resisting the external dorsiflexion torque may not be appropriate, resulting in significantly increased VGRF at the left leg. Landing with limited visual input in battlefield would be more dangerous than our standardized, practice-allowed lab testing. The characteristics of terrain are unfamiliar, and Soldiers have to focus on operation conditions instead of the task of landing itself. Plus, subjects did not carry weapons or wear protection gears in the current study. In battlefield, the weight of equipment can further place greater physical demands on Soldiers to perform landing tasks. The increased unpredictability can potentially amplify the differences we found with a relatively more prepared and planned movement. Altered knee kinematics and increased joint moments were found in reactive compared with planned stop-jump tasks.[7] Furthermore, previous studies found increased variability in electromyographic and kinematic patterns during landing without vision.[15,16] These may sum up into a higher chance of inadequate neuromuscular activations when landing at night. Considering the accompanied higher risk of night operation, it may be beneficial to develop training programs in attempt to improve Soldiers' kinematic and neuromuscular performance when vision is affected. It is unclear, however, whether kinematic or muscle activation patterns during landing can be trained to override the lack of visual input. An intervention program conducted on Air Assault Soldiers demonstrated that posture sway in anterior/posterior and medial/lateral directions under no-vision condition can be reduced via balance training with eyes closed.[29] It is also unclear whether such improvements are sustainable. Future research is encouraged to study the design and efficacy of potential training programs with vision deprived. Finally, increased BW or body mass index in military recruits may result in early discharge and higher risk of injury. Increased BW or body mass index in military recruits has been a concern in the U.S. Army. Future research is needed to evaluate whether the potential detrimental effects of the detected biomechanical differences further increase with increased BW.

The current study has its limitations. All subjects performed the WV condition first, practiced before real trials, and were blindfolded for the NV condition after they stepped onto the platform. As the height of the platform remained unchanged in this study, such design raises two potential issues. The first is potential practice effects. In a previous study, Santello et al[16] tested subjects for the NV condition first, varied the platform height, and blindfolded the subjects before stepping onto the platform. No practice effects in kinematics or VGRF were found across trials in either WV or NV condition.[16] Magalhaes and Goroso[30] found the first drop landing trial with vision removed induced prelanding EMG adaptations for the following trials, making muscle activation patterns similar to that observed with vision. However, Santello et al[16] suggested no such adaptation effect for both WV and NV conditions. The second issue is that the subjects were aware of the platform height. Liebermann and Goodman[15,18] allowed their subjects to view the height before dropping and found unchanged or decreased VGRF and earlier muscle firings in rectus femoris before initial contact. Santello et al[16], who detected increased VGRF and no difference in muscle activation timings, argued that viewing the platform height in advance may be used to plan the joint and muscle activation and compensate for the loss of visual input during dropping. Interestingly, our results of decreased maximum knee flexion and increased VGRF were comparable to Santello et al,[16] whereas our design was more similar to Liebermann and Goodman.[15,18] Thus, the current results do not support Santello's argument that viewing the platform height is sufficient to compensate the removal of visual input. It is more likely that even with some visual information gathered before dropping, the loss of vision still overrides an existing movement plan.

This research is among few studies investigating the effect of visual input on biomechanics of landing and was the only study recruiting subjects from military populations. We expect that the results of this study will provide insights for improving Soldiers' training and injury prevention.

CONCLUSION

Nighttime operations are known of greater risk of injury than daytime. The removal of vision alters Soldiers' landing kinematics and GRFs, potentially placing them under higher risk. Physical training to compensate for night-specific tasks is needed for Soldiers to establish a motor program of proper landing skills, and therefore reduce the effect of limited visual input.

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Less Body Fat Improves Physical and Physiological Performance in Army Soldiers

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ABSTRACT The purpose of this study was to compare physical and physiological fitness test performance between Soldiers meeting the Department of Defense (DoD) body fat standard (≤18%) and those exceeding the standard (>18%). Ninety-nine male 101st Airborne (Air Assault) Soldiers were assigned to group 1: ≤18% body fat (BF) or group 2: >18% BF. Groups 1 and 2 had similar amounts of fat-free mass (FFM) (66.8 ± 8.2 vs. 64.6 ± 8.0, p = 177). Each subject performed a Wingate cycle protocol to test anaerobic power and capacity, an incremental treadmill maximal oxygen uptake test for aerobic capacity, isokinetic tests for knee flexion/extension and shoulder internal/external rotation strength, and the Army Physical Fitness Test. Results showed group 1: ≤18% BF performed significantly better on 7 of the 10 fitness tests. In Soldiers with similar amounts of FFM, Soldiers with less body fat had improved aerobic and anaerobic capacity and increased muscular strength.

INTRODUCTION

In 1976, the Army Weight Control Program 600-9[1] (AR 600-9) underwent a significant revision, which resulted in combining the U.S. Army Physical Fitness and Weight Control Program regulations in response to concerns that Army personnel were becoming too sedentary, fat, and unable to maintain desired levels of physical fitness.[1] The primary objective of the AR 600-9 is to ensure that all Army personnel are able to meet the physical demands of their duties under combat conditions. It is a mandatory weight control program that uses body weight and percent body fat (% BF) to assist in establishing and maintaining health, optimal physical fitness, and operational readiness.[1]

There is great debate, however, over ideal body composition for military personnel to optimize physical fitness and performance on the battlefield. Identifying "ideal" body composition standards in military personnel is complicated by the diverse, multifaceted requirements of military training and missions. Unlike elite strength/power athletes who benefit from a higher body weight and greater lean body mass and elite endurance athletes who benefit from carrying less body weight and low fat mass, the tactical athlete engages in military training and missions that require adeptness in both of these fitness areas. Given these requirements, it appears that a large, lean body composition with less body fat would best meet the demands of military performance. The difficulty lies in the fact that the Army is recruiting from an American population that is 68% overweight/obese;[2] of this population, more than 9 million adults aged 17 to 24 are too overweight to join the military.[3] "Today's Soldiers are larger than ever before, a desirable Army trait—"large and in charge"—with appearance of fitness and formidable size."[4]

Scientific evidence, however, is equivocal regarding the impact a larger body size has on physical fitness and military performance in the contemporary Soldier. Research substantiates that excess body weight as fat-free mass (FFM) will improve performance on standardized strength tests, as well as physical tasks involving carrying and lifting.[5,6] If, however, the strength tests require moving body mass through space or if body mass serves as the external load, lean body mass is not associated with increased muscle strength performance.[7] Mattila et al.[8] found that lean body mass was not associated with muscle strength measured by standing long jump, push-ups, sit-ups, pull-ups, and back extension.[8] Additionally, because muscle mass does not proportionately increase with body mass, larger individuals may be at a disadvantage in maneuvering their own bodies.[9]

Excessive total body mass has been associated with impaired aerobic fitness[4] and performance on a variety of military readiness tests.[8,10–12] If excess weight is predominantly fat mass, research is consistent that higher % BF does not optimize fitness or performance.[8,10,11,13] A prospective study of 140 Army recruits showed that a 1% increase in fat shortened the 12-minute running distance by 19.3 meters.[8] Moreover, higher % BF has been shown to negatively affect military performance on tasks that require both strength and aerobic components such as loaded marching.[6,14]

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A report from the Armed Forces Health Surveillance Center revealed a drastic rise from approximately 25,000 to 70,000 active component military service members diagnosed as overweight between 1998 and 2008.[15] Given the ambiguity between "overweight" and "overfat," research is warranted to investigate whether there is an appropriate % BF that would significantly improve strength, aerobic, and anaerobic fitness compared to those with a higher % BF, regardless of total body weight.

The purpose of this study was to compare performance on physical and physiological tests between Soldiers meeting the Department of Defense (DoD) body fat goal (≤18%) and those exceeding the goal (>18%). It was hypothesized that male Soldiers with less % BF (≤18%) would perform better on physical and physiological fitness tests and the Army Physical Fitness Test compared to Soldiers with higher % BF (>18%).

METHODS

Subjects

Ninety-nine male subjects were recruited from the Army 101st Airborne Division (Air Assault) to participate in this study. Approval was obtained from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and the Human Research Protection Office as part of an ongoing research project focusing on injury prevention and performance optimization in the 101st Airborne Division (Air Assault).

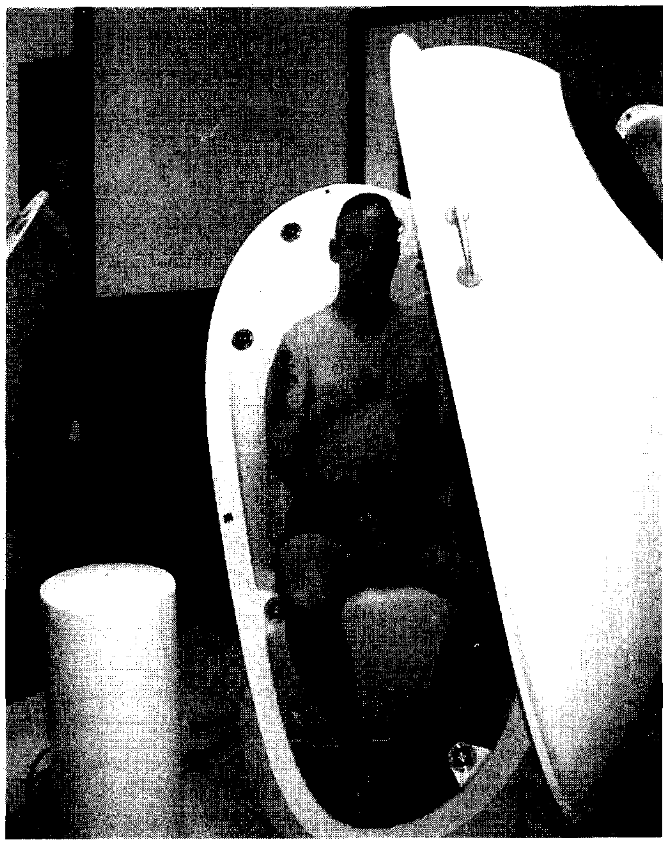

FIGURE 1. Body fat analysis.

Dependent Variables

Body composition, measured as % BF, was used to categorize subjects into groups on the basis of DoD body fat goals:[16] group 1: ≤18% BF and group 2: >18% BF. Physiological variables included anaerobic power (PNAP) and anaerobic capacity (MNAP); maximal oxygen consumption (VO_2max); peak isokinetic knee extension (AKE) and flexion (AKF); peak isokinetic shoulder internal (ASIR) and external rotation (ASER); and the Army Physical Fitness Test (APFT). Laboratory testing was performed in the Research Center for Injury Prevention and Human Performance at Fort Campbell by the same research associates on 2 separate days, with at least 24 hours separating each test day. Body composition, isokinetic strength tests, and anaerobic capacity were tested on day 1 and VO_2max was performed on day 2. The components of the APFT were performed on the same day on a separate occasion in a field setting. Although the primary purpose of the tests was to assess the Soldiers' strength and aerobic and anaerobic fitness, achieving and maintaining a high level of each fitness component is critical for Soldiers' combat survivability and overall operational effectiveness.[17,18]

Body Composition

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, California; see Figure 1) was used to measure body composition. The Bod Pod utilizes air-displacement plethysmography to measure body volume and calculate body density. The Bod Pod is a valid method of body composition measurement in comparison with the gold standard, hydrostatic weighing, in heterogeneous samples, and has been used to assess body composition across a variety of populations.[19-24] Intrasubject reliability within our laboratory has demonstrated reliability and validity (ICC = 0.98, SEM = 0.47% BF). The system underwent a standard calibration utilizing a 50.683 L calibration cylinder and an additional two-point calibration before each test. Subjects wore spandex shorts and swim caps. Body volume was measured until two consistent measurements were achieved. Predicted lung volume and an appropriate densitometry equation were used to calculate % BF.[25] Subjects were assigned to group 1: ≤18% BF or group 2: >18% BF to compare the results on the following physiological fitness tests.

Anaerobic Power

Anaerobic power and capacity were measured using a VeloTron cycling ergometer (RacerMate, Seattle, Washington; see Figure 2) during a Wingate protocol.[26] The Wingate protocol is highly valid and reliable[27] and has been significantly correlated with anaerobic run test performance.[28,29] The ergometer was calibrated by pedaling to a velocity according to factory recommendations. Proper seat and handlebar adjustments

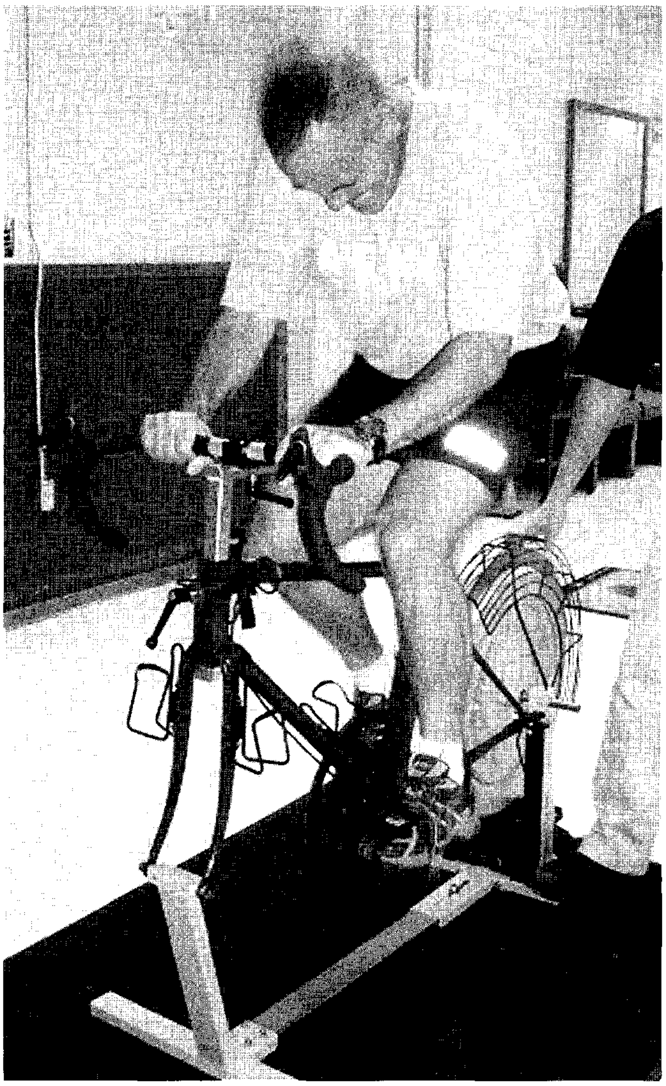

FIGURE 2. Wingate test.

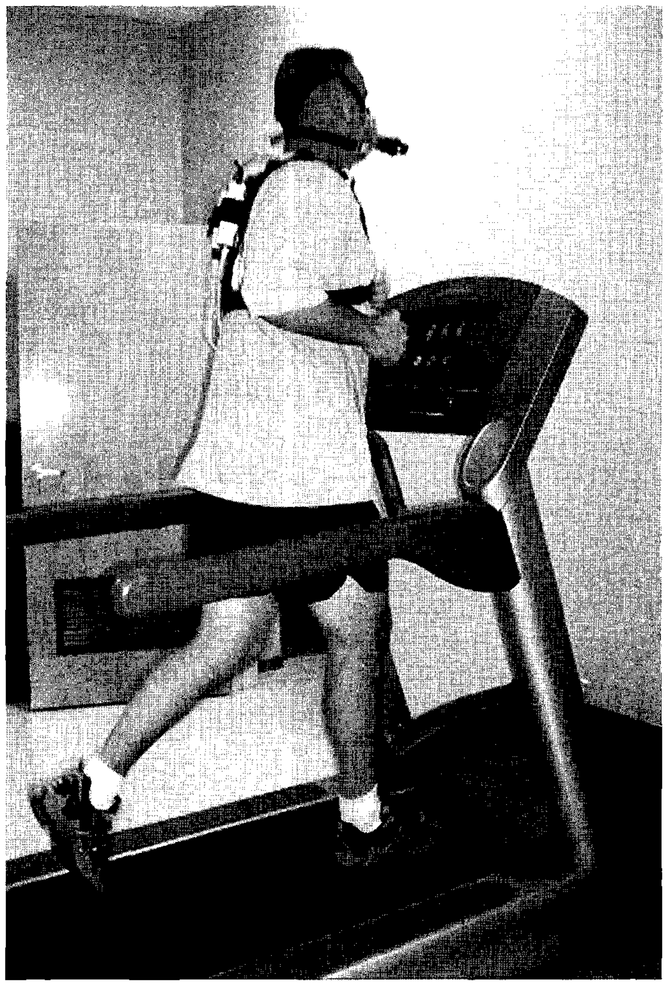

FIGURE 3. Maximal oxygen uptake test.

were made before the subject's feet were secured to the pedals, and a warm-up cycle at a self-selected cadence was initiated at 125 watts (W). Subjects underwent a 50-second cycling protocol, in which they pedaled at 125 watts for 20 seconds, and then performed a maximal effort sprint for 30 seconds against a braking torque of 9% body weight. Standard verbal instructional cues were provided during the test. Anaerobic power was reported as the peak watts normalized to body weight produced during the first 5 seconds of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30 seconds (W/kg).

Maximal Oxygen Uptake

A portable metabolic system (Oxycon Mobile; Viasys, San Francisco, California; see Figure 3) was used to assess maximal oxygen consumption during an incremental treadmill test. The Oxycon Mobile is a valid metabolic system, showing less than 3% difference compared to simulated VO_2 during a maximal cardiopulmonary exercise test.[30] The instrument was calibrated with known gas mixtures and measured values corrected to standard temperature, pressure, and density. A heart rate monitor (Polar USA, Lake Success, New York) was worn by the subject around the chest at the level of the zyphoid process. The subject performed a warm-up at a self-selected speed on the treadmill for 5 minutes before testing. A modified incremental protocol[31] was used to reach VO_2max, with subjects running at a constant speed and a 2.5% increase in grade at the end of each 3-minute stage. The subjects' speed was determined as 70% of the mile pace from their 2-mile run time during the APFT. Subject termination was determined by volitional fatigue. Maximal VO_2 is reliable and highly predictive for evaluating differences in aerobic fitness across populations[6] and was reported normalized to body weight (mL/kg/min).

Army Physical Fitness Testing

The APFT was conducted by the individual military units on a separate occasion. Push-up and sit-up tests were performed according to the Army standard protocol,[32] which records the maximal number of repetitions completed in each 2-minute timed period. Push-ups and sit-ups are widely accepted as valid indicators of muscle strength and endurance.[7]

A 2-mile run timed test was conducted and the amount of time needed to run the distance of 2 miles was recorded.[32] Distance runs are highly correlated with aerobic capacity.[6,7,33]

Musculoskeletal Assessment

Bilateral isokinetic strength of the knee (flexion/extension) and shoulder (internal/external rotation) was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Shirley, New York; see Figure 4). The reliability of isokinetic strength testing had been established in our laboratory (ICC = 0.73–0.97) for peak torque/body weight.

Isokinetic knee extension and flexion dynamometry are highly reliable (ICC = 0.96–0.97 and ICC = 0.93–0.98, respectively)[34–37] and valid[36,38,39] measures of quadriceps and hamstring muscle performance that identify military personnel at risk for overuse knee joint injury,[40–44] and significantly predict hopping, leaping, and jumping ability ($r = 0.62–0.92$, $p < 0.05$ for extension and $r = 0.65–0.69$, $p < 0.05$ for flexion)[45–47] as well as straight-line and agility sprint performance ($r = -0.42$ to -0.51, $p < 0.05$ for extension and $R > 0.55$, $p < 0.05$ for flexion).[45,48–50]

Isokinetic shoulder internal rotation and external rotation dynamometry is a highly reliable (ICC = 0.78–0.92)[51–53] and valid[36,38,39] measure of rotator cuff muscle performance, of which optimal function is considered critical in shoulder injury prevention programs.[54,55]

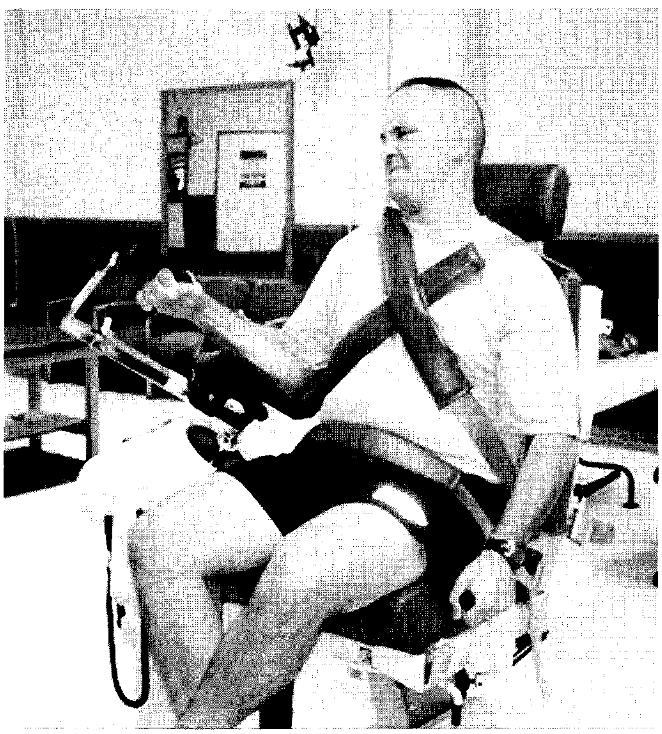

FIGURE 4. Isokinetic shoulder strength test.

To test isokinetic knee and shoulder strength, the subjects were properly fitted to the chair of the device by aligning the axis of joint rotation to the dynamometer axis. For knee strength, the subject was seated with the hip at 90°, and for shoulder strength, the subject was seated with their arm securely fitted to the dynamometer's arm at 30° of shoulder abduction. Padded straps were used to prevent extraneous movements during the test. Dynamometer range of motion stops and limb weight/gravity correction were set. The subject performed three practice trials at 50% maximal effort and three practice trials at maximal effort followed by a 60-second rest period. Peak isokinetic torque for AKE, AKR, ASIR, and ASER was measured across five, maximal effort repetitions (concentric/concentric at 60°/second) and reported normalized to percent body weight.

Statistical Analysis

Data were examined to evaluate the assumptions of normality and homogeneity of variance. Descriptive statistics (measures of central tendency and measures of dispersion) were calculated for all variables. Because the assumption of normality was met for most, but not all of the variables, Mann-Whitney *U* tests and calculation of the Spearman correlation coefficient were performed. The results of the nonparametric test agreed with the results of the corresponding parametric test (independent samples *t*-test and Pearson correlation coefficient) with respect to significance of the results (Table II). Though both parametric statistics for normally distributed data and nonparametric statistics are presented in Tables I and II, parametric statistics are reported in the text for all variables (mean ± SD). In post hoc analysis, there was one case (ASIR relative to FFM between groups) when the nonparametric and parametric tests disagreed; in this case, both statistics are presented as this also was a variable that did not meet the assumptions of normality.

For variables where the assumption of homogeneity of variance for the two-sample *t*-test for independent samples was not met, the *t*-test for unequal variances (Satterthwaite approximation) was used. Statistical significance was set at 0.05 (two-sided) a priori.

The performance variables included three distinct families—aerobic/anaerobic capacity (PNAP, MNAP, and VO_2max), APFT (push-ups, sit-ups, and run), and muscular strength variables (ASIR, ASER, AKF, and AKE). The Bonferroni procedure was applied within each family of performance variables to correct for the multiple comparisons.

Effect size for the performance variables was calculated using the absolute difference between means and the pooled SD. Statistical analysis was done using SPSS 17.0 (SPSS, Chicago, Illinois.).

RESULTS

Table I lists the demographic and anthropometric data for all subjects. Significant differences were found between group 1: ≤18%

TABLE I. Demographic and Anthropometric Data of Group 1: ≤18% BF and Group 2: >18% BF

	Group 1 (≤18% BF)						Group 2 (>18% BF)							
	n	Median	1st Q	3rd Q	Mean	SD	*n*	Median	1st Q	3rd Q	Mean	SD	Mann Whitney *U*	*T*-test
Age (Y)	44	25.5	22.0	29.0	26.6	6.1	55	30.0	24.0	38.0	30.6	7.2	0.005*	0.004*
Height (in)	44	69.5	68.0	72.0	69.6	3.4	55	70.0	68.0	71.5	69.8	2.5	0.817	0.703
Weight (lbs)	44	170.0	152.5	185.0	169.8	21.2	55	187.9	172.0	215.0	192.5	27.7	0.000*	0.000*
BMI (kg/m^2)	44	24.9	23.0	25.9	24.7	2.6	55	26.8	25.4	29.9	27.7	3.1	0.000*	0.000*
BF (%)	44	14.0	11.0	16.0	13.3	3.7	54	25.2	21.1	29.8	26.0	5.4	0.000*	0.000*
Service (Y)	42	4.5	2.8	7.6	6.0	5.2	53	8.0	3.8	14.5	9.0	6.1	0.009*	0.011*
FFM (kg)	44	66.2	60.6	72.8	66.8	8.2	54	63.3	58.4	69.6	64.6	8.0	0.186	0.177
FM (kg)	44	10.7	7.9	13.1	10.3	3.4	54	21.2	16.8	29.0	23.1	7.1	0.000*	0.000*

*Variable showed significant differences in medians and means between groups utilizing Mann Whitney *U* and *T*-test with α set a priori at $p = 0.05$.

TABLE II. Comparison of Performance Variables between Group 1: ≤18% BF and Group 2: >18% BF

	Group 1						Group 2								
	n	Median	1st Q	3rd Q	Mean	SD	*n*	Median	1st Q	3rd Q	Mean	SD	Mann Whitney *U*	*T*-test	Effect Size
PNAP (W/kg)	37	12.9	11.8	14.2	13.1	1.8	49	12.1	10.7	13.9	12.4	2.1	0.143	0.117	0.35
MNAP (W/kg)	37	8.3	7.8	8.7	8.3	0.6	49	7.3	6.7	8.0	7.2	1.0	0.000**	0.000**	1.23
VO_2max (ml/kg/min)	44	52.1	48.6	55.6	52.2	5.4	55	44.1	39.4	47.7	44.1	6.8	0.000**	0.000**	1.32
Push-Ups (2 min^{-1})	36	76.5	64.3	85.8	78.2	18.5	38	68.5	54.0	75.0	65.7	13.9	0.003**	0.002**	0.76
Sit-Ups (2 min^{-1})	36	74.5	58.0	84.5	73.6	16.2	38	70.5	61.5	82.8	73.1	14.0	0.981	0.892	0.03
Run Time (min)	36	14.8	13.2	16.8	15.2	2.3	38	15.3	13.6	16.2	15.1	2.0	0.955	0.874	0.04
ASIR (% BW)	44	62.4	53.6	75.1	66.1	16.3	54	50.0	37.9	59.3	50.4	14.5	0.000**	0.000**	1.01
ASER (% BW)	44	44.0	40.1	50.5	45.4	7.7	54	36.0	31.0	41.7	36.6	7.4	0.000**	0.000**	1.16
AKF (% BW)	44	125.9	113	146.6	127.9	23.9	54	104.0	85.1	122.6	103.6	26.6	0.000**	0.000**	0.96
AKE (% BW)	44	265.5	229.4	289.5	263.5	49	54	223.0	186.0	251.4	219	41.7	0.000**	0.000**	0.98

*Statistically significant at the 95% confidence level. **Statistically significant after application of the Bonferroni procedure within each family of performance variables. All numbers have been rounded except for *p*-values.

BF and group 2: >18% BF for body weight, BMI, % BF, age, and years of service. There were no significant differences between groups for height and FFM. Thus, the difference in body weight was due to the difference in the amount of fat mass (FM) and not FFM.

Because the correlations between both age and years of service and the fitness/performance variables were weak (absolute value < 0.3, except for the Pearson correlation coefficient [−0.314] between years of service ASER), no further adjustments were made for age or years of service in studying the association between BF and physical fitness variables.[56,57]

Subjects in group 1: ≤18% BF who met the DoD body fat goal performed significantly better than those in group 2: >18% BF on 7 of the 10 physical and physiological tests performed (Table II). Group 1: ≤18% BF had significantly higher MNAP and VO_2max than group 2: >18% BF ($p \leq 0.001$). Of the APFT, only push-ups were significantly different between groups, with Soldiers in group 1: ≤18% BF having significantly higher scores than Soldiers in group 2: >18% BF ($p = 0.002$). Group 1: ≤18% BF performed significantly better on all measures of isokinetic strength, including AKE, AKF, ASIR, and ASER ($p < 0.001$).

A post hoc analysis was performed to calculate absolute isokinetic strength and isokinetic strength normalized to FFM. Absolute strength values were significantly higher in group 1: ≤18% BF than group 2: >18% BF for ASIR (51.09 ± 14.47 vs. 43.88 ± 13.67, $p = 0.013$) and ASER (34.96 ± 7.19 vs. 31.90 ± 7.29 N*m, $p = 0.040$), and while not statistically significant, group 1: ≤18% BF had higher absolute AKE (203.52 ± 46.76 vs. 190.51 ± 41.02 N*m, $p = 0.146$) and AKF strength (98.96 ± 23.71 vs. 89.98 ± 24.23 N*m, $p = 0.069$).When isokinetic strength was normalized to FFM, there were no significant differences between group 1: ≤18% BF and group 2: >18% BF for ASIR (52.4 ± 8.6 vs. 49.4 ± 9.1% FFM, $p = 0.102$), AKE (304.1 ± 55.5 vs. 296.0 ± 54.7% FFM, $p = 0.475$), and AKF (147.6 ± 27.5 vs. 139.6 ± 33.1% FFM, $p = 0.202$). Isokinetic ASIR relative to FFM was higher in group 1: ≤18% BF (76.2 ± 18.4 vs. 67.9 ± 18.1% FFM, *t*-test $p = 0.026$, Mann-Whitney U $p = 0.054$).

DISCUSSION

In recent years, the Army has been increasingly concerned with the rise in body weight/fat and its effect on physical fitness, battlefield performance, and military appearance. Results from this study suggest that in Soldiers with similar amounts of FFM, those with less body fat and thus weight performed better on tests of anaerobic and aerobic capacity, push-ups, and isokinetic knee and shoulder strength. In general, this study substantiates, if the excess body weight is from higher body fat mass, overall physical fitness is compromised.

Since excess body fat is noncontractile, does not assist in force generation, increases the force requirements of muscles, weighs the body down during acceleration, and requires more energy to move the heavier mass through space, it is not surprising that it has a negative impact on aerobic performance.[58,59] In this study, group 1: ≤18% BF performed significantly better on the VO_2max test than group 2: >18% BF. In addition, the correlation between % BF and VO_2max was strong ($r = -0.633$, $p < 0.001$), a finding consistent with studies reporting a negative relationship between aerobic capacity and % BF.[4,60] This relationship corresponds to the physiological condition where the capacity for body propulsion is decreased as % BF, or nonenergy-producing tissue, increases.[59] Figure 5 shows that there is some variability in the relationship between % BF and the VO_2max, but in general, aerobic capacity improves with a reduction in % BF.

Sharp et al.[6] reported no significant change in VO_2max in a cohort of Army Soldiers tested at two time periods, 1978 and 1998 (VO_2max 50.7 ± 4.8 and 50.6 ± 6.2, respectively), despite a significant increase in body fat (16.2 ± 5.3% and 18.7 ± 4.8%, $p < 0.05$).[6] The increase in body fat from 16.2% to 18.8%, although statistically significant, is a range of body fat that is below the most stringent maximal allowable body fat level for Army personnel. From our data, as % BF increases above approximately the 15% threshold, there is a more dramatic decrease in aerobic capacity (see Figure 5).

Maximal oxygen uptake and 2-mile run times have been reported to be highly correlated ($r = -0.76$ to -0.91).[5,6,61-63] In the present study, there was a very weak nonsignificant association between 2-mile run time and VO_2max. It is unknown whether subjects performed the APFT at maximal effort during testing or whether they merely performed each task to pass the Army standard requirements. Other researchers have also raised questions regarding the extent to which a Soldier performs maximally vs. achieving the minimal scores needed to pass the AFPT.[6,64] The weak association would substantiate the notion that Soldiers did not perform at maximal effort on the 2-mile run test. This limitation may in part explain why Soldiers in group 1: ≤18% BF did not perform significantly better than Soldiers in group 2: >18% BF on the sit-up and the 2-mile timed run tests.

Limited previous research has evaluated the impact of body composition on anaerobic power and anaerobic capacity. A study examining the relationship between muscle fiber type, body composition, and anaerobic power utilizing a cycle ergometer test found that the morphological variables that had the highest positive correlation to maximal power output were total body mass and fat free mass ($r = 0.54$ and 0.57, respectively).[65] These results may help to explain why there was no significant difference between groups for anaerobic power in our study. Since our results showed that anaerobic capacity was significantly better in group 1: ≤18% BF, this suggests that leaner Soldiers perform better in anaerobic tasks lasting for a longer duration. Figure 6 shows that in general, there is a decrease in anaerobic capacity as % BF increases, with a sharper decline in performance above approximately the 20% body fat level.

Not only is excess body fat negatively associated with aerobic and anaerobic capacity; it has been negatively correlated with measures of strength that use the body as the principal resistance (push-ups, vertical jump) as well as those that do not (isokinetic tests, 1-repetition max).[7,8] Results of the strength testing in this study are in agreement with these findings, in which push-ups and isokinetic AKE, AKF, ASIR, and ASER were significantly, negatively correlated to % BF.

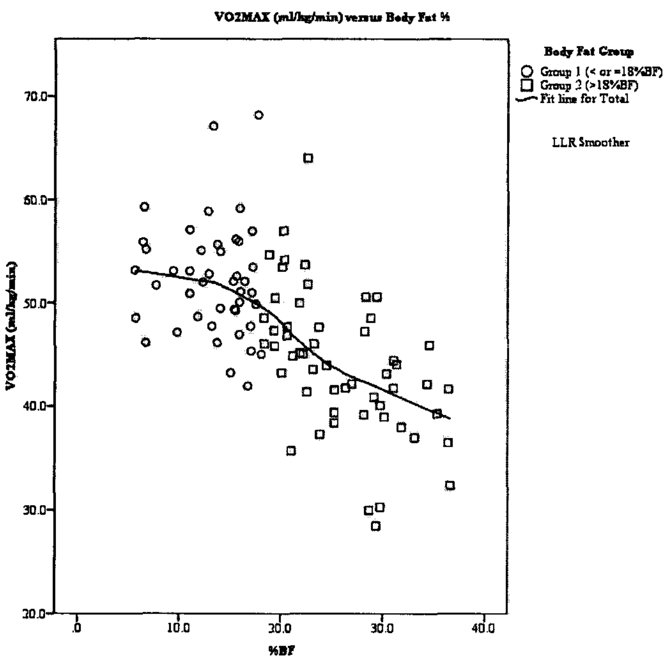

FIGURE 5. Maximal oxygen uptake plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

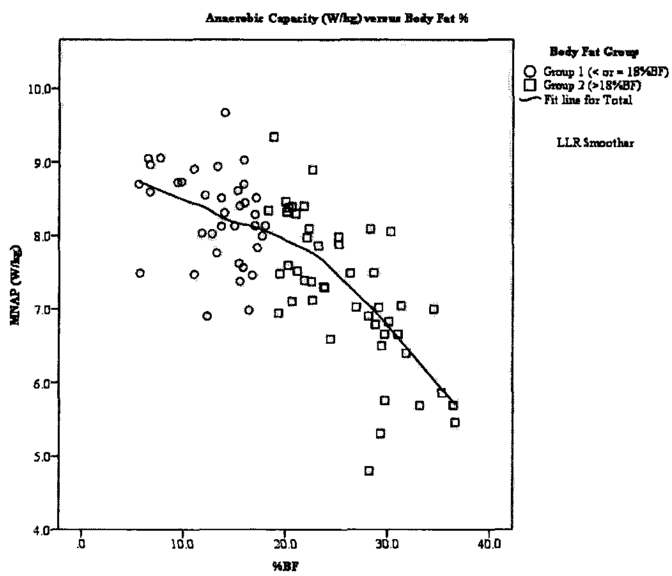

FIGURE 6. Anaerobic capacity plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

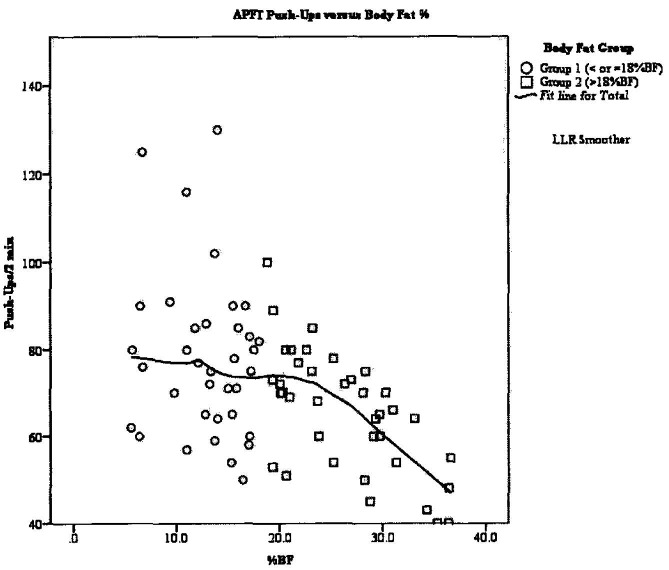

FIGURE 7. APFT push-up score plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

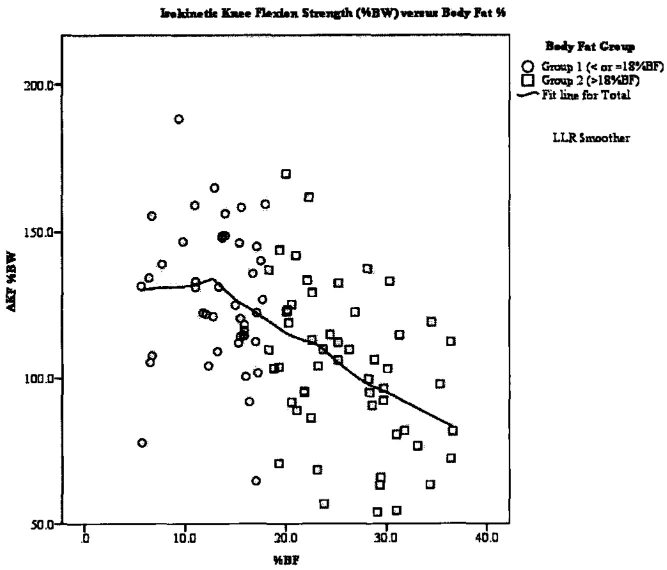

FIGURE 8. Isokinetic knee flexion strength plotted against body fat percent. Circles denote Group 1 (< or = 18% BF) and squares denote Group 2 (>18% BF).

Sit-ups, however, were poorly correlated to % BF. The scatter plot in Figure 7 shows that there is more variability in the relationship between % BF and push-up performance in the lower body fat range; however, above the 20% body fat level, there is a more dramatic decrease in number of push-ups performed.

In a study examining the association between body composition and physical fitness, 140 Army recruits completed strength testing including standing long jump distance; number of sit-ups, push-ups, and pull-ups; back extension; and a 2-mile run.[8] Researchers concluded % BF was the strongest predictor of muscle strength and running performance and that the amount of muscle mass was not related to muscle strength. Although it is generally accepted that as body mass increases, both FFM and strength increase, muscle strength does not proportionately increase with total body mass.[7] There is a point at which the power produced by the higher amount of FFM is not enough to offset the additional body weight and the resistance created increases the energy requirement to perform the work.[9] This may in part explain why Soldiers in our study with less body fat and body weight but similar amounts of FFM (Table II), performed better on the majority of physical fitness tests. Figure 8 depicts the relationship between AKF and % BF, which shows some individual variability, but in general, as % BF increases, knee flexion strength decreases, with a sharper decline at approximately the 15% BF level.

In examining the impact that FFM had on physical performance, Pearson correlation coefficients for FFM and 10 physical fitness tests revealed a very weak, nonsignificant (r = 0.002–0.164) relationship. Further, when the isokinetic strength tests were normalized to FFM, there were no significant differences between groups except for ASIR, which trended higher for group 1: ≤18% BF. When normalized to total body mass, each measure of isokinetic strength was significantly higher in group 1: ≤18% BF, suggesting that the contribution of fat mass to total body mass accounted for the relative decrease in performance. The results of this study reinforce previous research showing that despite possessing similar levels of absolute FFM, individuals with less % BF possess greater levels of aerobic capacity and strength.[8,10,14,66]

The relationship between FFM and muscle strength and endurance is stronger in tests that involve carrying a load and lifting.[9,67] Vogel et al.[59] reported that absolute lifting capacity is directly related to FFM and not related to % BF in men.[59] However, since % BF in contemporary Soldiers is higher, there may be a point in which this higher amount of fat will also negatively impact absolute lifting capacity. Although our strength tests did not directly measure load carriage ability or overhead lifting, the absolute peak isokinetic strength values for ASIR and ASER were significantly greater in group 1: ≤ 18% BF, and while not significant, AKE and AKF showed similar trends. This suggests that in our population, the leaner subjects were able to produce greater absolute strength despite having significantly less total mass. Future studies may benefit from including loaded carry and maximal lifting tests to evaluate whether higher body weight provides a performance benefit or detriment and how that affects the other areas of physical fitness and military performance.

Currently, there is debate over the concept of "large and in charge" body size and how it impacts overall physical fitness and military performance. Critics of the current body weight and fat standards argue that heavier Soldiers perform better on a variety of military tasks such as lifting, pushing, and carrying external loads and that these job tasks are required with greater frequency in specific military occupational specialties (MOS). Although a higher body weight may provide some benefit to certain military tasks, carrying excess weight, as fat, is associated with poor physical fitness. One of the missions of military training is to improve physical fitness as it is generally accepted that this will increase the likelihood of success in battle.[68,69] Blount et al.[68] reported that a Soldier who is more physically fit can cover a longer distance in a shorter time than someone who is less fit, reducing time in the enemy's line of fire. Excess body fat may have a negative impact on important battlefield requirements including low and high crawl speed and endurance and climbing various terrains for long distances.[68] As the % BF of today's Soldiers continues to rise, research is warranted to determine body fat levels that are optimal for maximizing a wide range of physical fitness parameters and indicators of combat readiness, and further, the impact of losing excess fat on improving military fitness and performance.

The outcomes of this study present practical applications to the military population not only in improving a Soldier's physical fitness and thus military readiness, but helping to reduce a Soldier's risk of injury. Knapik et al.[70] reported that Soldiers with lower aerobic fitness and muscle strength had a higher occurrence of musculoskeletal injuries. Essentially, individuals with excess % BF may possess physiological fitness and musculoskeletal strength deficits, reduced military readiness, and increased risk for unnecessary injury.

CONCLUSIONS

As the body weight/fat of military personnel continues to rise, it is important to identify the impact it has on military training and combat. It is important for the military to employ techniques that provide more direct measures of body fat and FFM to accurately identify Soldiers with excess weight from body fat. This study provides supportive evidence that if the increase in body weight is due to excess body fat, physical fitness is compromised, which ultimately affects military preparedness. Future research is warranted to examine the direct relationship between body composition and physical readiness, which is more specific to a Soldier's MOS, tactical activities, and combat effectiveness.

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Minimal Additional Weight of Combat Equipment Alters Air Assault Soldiers' Landing Biomechanics

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ABSTRACT The additional weight of combat and protective equipment carried by soldiers on the battlefield and insufficient adaptations to this weight may increase the risk of musculoskeletal injury. The objective of this study was to determine the effects of the additional weight of equipment on knee kinematics and vertical ground reaction forces (VGRF) during two-legged drop landings. We tested kinematics and VGRF of 70 air assault soldiers performing drop landings with and without wearing the equipment. Maximum knee flexion angles, maximum vertical ground reaction forces, and the time from initial contact to these maximum values all increased with the additional weight of equipment. Proper landing technique, additional weight (perhaps in the form of combat and protective equipment), and eccentric strengthening of the hips and knees should be integrated into soldiers' training to induce musculoskeletal and biomechanical adaptations to reduce the risk of musculoskeletal injury during two-legged drop landing maneuvers.

INTRODUCTION

Musculoskeletal injury is a persistent and major health concern for individuals who are responsible for the medical care of military personnel. According to the Armed Forces Epidemiological Board (AFEB), injuries "impose a greater ongoing negative impact on the health and the readiness of U.S. armed forces than any other category of medical complaint during peacetime and combat."[1] More casualties have been caused among U.S. troops by noncombat injuries and disease than by combat.[2] Data presented to the AFEB's Injury Control Work Group by scientists from Navy and Army research organizations, and published military and civilian epidemiologic studies has revealed that the most common types of injuries seen in military populations are unintentional musculoskeletal overuse injuries.[3] A review of the medical treatment records in a group of 298 male infantry soldiers showed that musculoskeletal injuries were very common; musculoskeletal pain was the most common diagnosis followed by strains. Also, a higher cumulative incidence of soldiers with musculoskeletal injuries was associated with reduced physical fitness (2-mile run and sit-ups).[4] A study of data in an Army database of all hospital admissions (caused by an external injury) for active duty personnel showed that during a 6-year period, 11% (13,861) of the patients had injuries sustained during sports or physical training. Of these, musculoskeletal injuries were very common (fractures, 33%; sprains/strains, 29%; and dislocations, 15%). Sports and Army physical training injuries accounted for a significant amount of lost duty time.[5] An analysis of the Navy Physical Evaluation Board data showed that the most common diagnostic categories of cases were musculoskeletal disorders (43%) and injuries and poisonings (15%).[6] Recently, a survey by Sanders et al.[7] among military personnel involved in Operations Iraqi Freedom and Enduring Freedom revealed that 34.7% of soldiers reported noncombat injuries.

Musculoskeletal conditions and injuries are the leading causes of hospitalization in the U.S. Army, accounting for 31% of all hospitalizations in 1992.[8] Orthopedic and musculoskeletal issues accounted for 53% of all U.S. Army injury cases that were reviewed by the disability evaluation process of the physical evaluation board in 1994.[9] Similarly, 58% of such cases in 2005 in the U.S. Navy were caused by musculoskeletal conditions and injuries.[6] The high rate of overuse injuries adversely affects military training, resulting in lost days and increased medical costs.[10] The annual cost of injury-related disability in the military had exceeded $750 million in the mid-1990s,[1,9] and the annual expenditure of the U.S. Department of Defense to treat musculoskeletal injuries had been $600–750 million before 2001.[11] Such injuries will have long-term consequences even after individuals have left active duty. For example, among the veterans returning from Iraq and Afghanistan who have sought Veterans Administration health care between 2002 and 2006, 42% were related to musculoskeletal issues such as joint and back disorders.[12]

The knee is one of the most common sites of musculoskeletal injury in the military, accounting for 10–34% of all injuries among different military groups from Army infantry to naval special warfare trainees.[3] The mechanism responsible for knee injuries in the military has not been clearly outlined, but they are hypothesized to be similar to the mechanism responsible for knee injuries in athletes. Most traumatic noncontact knee injuries occur during demanding athletic tasks that include sudden deceleration, landing, and pivoting

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maneuvers,[13] which are all prevalent in military training, tactical operations, and sports activities. Among these tasks, landing from a raised platform may be one of the most critical and the most common. Landing is involved widely in infantry soldiers' training and operations, such as jumping off the back of a vehicle, traversing a ditch, and landing after a climb over a wall or other obstacle.

These landings typically induce dangerously high ground reaction forces, which will be transferred through the knees. Biomechanical and epidemiological research has linked several dangerous kinematic and kinetic characteristics during landing to a greater risk of noncontact anterior cruciate ligament (ACL) and secondary injuries in athletes.[14,15] Our own research has demonstrated that groups at risk for knee injury perform landing and cutting maneuvers with dangerous landing positions, which includes greater ground reaction forces, altered electromyographic activity, and increased joint loading.[16–19] Because of similar injury mechanisms in the military, the same models employed to study biomechanics in athletes are appropriate for use in military populations.

Although soldiers perform very different tasks than typical athletes, soldiers must be able to perform and react similarly and can be considered tactical athletes. While athletes can sometimes modify equipment (lighter shoulder pads in football for instance), soldiers do not have the convenience of improving their agility in the field by using lighter equipment. Instead, soldiers must wear the required heavy and uniformed protective equipment and must also carry weapons, ammunitions, communication devices, and other equipment for combat. The weight a soldier carries while marching has increased throughout the past century.[20] Such additional weight can alter soldiers' normal body movement patterns, increase joint stress, and potentially increase their risk of suffering musculoskeletal injuries. For example, Army officials have reported that the 60–70 kilograms of weight (approximately 65% to 75% of the soldier's body weight [BW]) that U.S. soldiers routinely carry in the mountains of Afghanistan has increased the number of soldiers who have been categorized as "nondeployable" because of musculoskeletal injuries.[21] Previous research studies demonstrated that carrying a military rucksack (approximately 15%–30% of the soldier's BW) can initiate compensatory kinetic response at the knees,[22] elevate the forces applied on the upper and lower back,[23] and increase the thoracic and lumbar spine curvature.[24] The additional weight may also alter landing kinematics and ground reaction forces. Kulas et al.[25] studied the effect of a vest of 10% BW on recreationally active civilian participants performing two-legged drop landing from a 45-cm-height platform. They reported increased angular impulse and energy absorption but no significant change in maximum knee flexion angles, whereas ground reaction forces and knee valgus angles were not mentioned.[25]

The biomechanical response to additional weight has not been extensively studied in a military population. Therefore, the main purpose of this study was to investigate the effects of additional weight on soldiers' kinematics and kinetics and their potential implication on lower extremity musculoskeletal injury using similar biomechanical models we have previously employed in athletes.[16–19] Although the effects of additional weight should be observed throughout the lower extremity, we chose the knee joint as the main focus of this study. We used standard military body armor, a helmet, and a rifle to represent the minimal additional weight a soldier would carry in a combat setting. As a part of our ongoing 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program, soldiers from the 101st Airborne Division (Air Assault) participated in this study. We hypothesized that wearing body armor, a helmet, and carrying a rifle would result in greater knee flexion and knee valgus angles at initial foot contact, greater maximum knee flexion angle, prolonged time from initial foot contact to maximum knee flexion, greater maximum vertical ground reaction forces (VGRF), and a prolonged time from initial foot contact to maximum VGRF, compared to not wearing the additional weight. This study is among a limited number of investigations examining the effect of additional weight on biomechanics of drop landing and is the only one recruiting participants strictly from a military population. We expect the results of this study will provide evidence-based insight to modify soldiers' training, accounting for the necessary loads carried during combat, to reduce the risk of injury.

Methods Participants

Seventy 101st Airborne (Air Assault) soldiers volunteered to participate in this study (age, 28.8 ± 7.1 yr; height, 1.78 ± 0.07 m; weight, 84.1 ± 12.8 kg). To be included, potential participants must have been 18- to 45-year-old males from the 101st, with no history of concussion or mild head injury in the previous year, no upper extremity, lower extremity, or back musculoskeletal pathology in the past 3 months that could affect the ability to perform the required tests, and no history of neurologic or balance disorders. All participants were cleared for active duty without any recent prescribed duty restrictions. Participants provided informed consent before participation. The current study was approved by the university's institutional review board (0506094), Eisenhower Army Medical Center (DDEAMC 07-16), Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office (HRPO A-14020). All tests were conducted at our Human Performance Research Laboratory, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

Instrumentation

Six high-speed cameras (Vicon, Centennial, CO) operating at 200 Hz were used to capture the participants' kinematic data. Vertical ground reaction forces were measured using two Kistler force plates (Kistler, Amherst, NY) at a frequency of 1,200 Hz. The soldiers used their own personalized interceptor body armor (IBA) (Point Blank Body Armor, Pompano Beach, FL) and advanced combat helmets (Gentex, Simpson, PA) for the test. An assault rifle replica (M4 carbine model) was provided by the researchers. The total weight of the interceptor body armor, helmet, and rifle replica was 15.0 ± 3.7 kg, or 18.0 ± 4.3% compared to each participant's BW. The authors recognize the actual weight carried by the soldiers will vary considerably depending on their work demands and could not control for potential differences between soldiers. The weight of the IBA, helmet, and rifle, however, represented the minimal additional required weight to be carried by the soldiers as part of tactical operations excluding the combat uniform and boots not worn as part of this study.

Procedures

Sixteen reflective markers were placed bilaterally on the participants' anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleoli, posterior calcanei, and second metatarsal head (dorsal surface), according to Vicon's Plug-in Gait model (Vicon). The lateral thigh markers (midfemur) were placed in line between participants' greater trochanter (as palpated) and the lateral femoral epicondyle marker, and the lateral shank markers were placed in line between the lateral femoral epicondyle marker and lateral malleolus markers. A static trial was captured for each participant in the anatomical position and served as the baseline for joint angle calculations. The participants were asked to perform two-legged drop landings from a platform of 50 cm high under two conditions: with and without wearing the IBA, helmet, and rifle; henceforth referred to as the IBA condition (Fig. 1) and non-IBA condition (Fig. 2), respectively. Participants were instructed to stand near the edge of the platform and drop off when the researchers gave the command. The participants were to land on both feet on the two force plates and remain standing for 2 seconds after regaining their balance. The task was described and demonstrated by the researcher. For each condition, the participants were given at least three practice trials. All trials for both conditions were performed on the same day with approximately 30–60 seconds in between trials within each condition and approximately 5 minutes between the two conditions. Trials during which the participants did not drop off the platform properly, failed to regain balance, touched the ground off the force plates, or did not land on the force plates were rejected.

Data Reduction

The 3D coordinates of the video-captured reflective markers were reconstructed and synchronized with the VGRF data using Vicon Nexus software (Vicon Motion Systems,

FIGURE 1. Two-legged drop landing task, IBA condition.

FIGURE 2. Two-legged drop landing task, non-IBA condition.

Centennial, CO). We used a general cross-validation Woltring filter to smooth the reconstructed 3D coordinates.[26] The Vicon Plug-in Gait model uses ASIS and PSIS markers to estimate the position of hip joint centers. However, to account for coverage of the ASIS markers by the IBA, we placed these markers on the IBA itself. Unfortunately, this invalidated the 3D joint angle calculations as they no longer reflected the anatomical landmarks on which they were intended. Therefore we decided to use 2D angles defined only by those markers on the legs, which were not affected by the ASIS markers.

The filtered *x*, *y*, and *z* coordinates and force plate data were processed with a custom Matlab (The MathWorks, Natick, MA) program to calculate joint angles and identify critical events. The knee flexion angle was defined as 180° minus the inner angle formed by lateral thigh, lateral knee, and lateral malleolus projected on the sagittal plane. The knee valgus angle was defined as 180° minus the inner angle formed by the three markers projected on the frontal plane. The joint angles during the dynamic tasks were corrected by the baseline angles from the static trial. Initial contact was defined as the point at which the vertical ground reaction forces exceeded 5% of the participant's body mass. Variables assessed in the current study included knee flexion and knee valgus at initial foot contact, maximum knee flexion, time to maximum knee flexion, maximum VGRF, and time to maximum VGRF. Three trials for each participant were averaged for statistical comparisons.

Statistical Analysis

Dependent *t*-tests were used to examine the differences of selected variables with (IBA) and without (non-IBA) wearing IBA. Each participant would serve as his own control. Statistical analyses were performed using SPSS software (SPSS, Chicago, IL). The α level was set at <0.05.

RESULTS

The results are presented in Table I. The participants demonstrated no statistical difference between the IBA and non-IBA conditions for knee flexion or knee valgus angles at initial contact. Under the IBA condition, the participants had significantly greater maximum knee flexion and greater maximum VGRF; the time from initial contact to these peak values were also significantly longer.

DISCUSSION

Equipment for personal protection and combat purposes places additional weight on the soldiers' bodies, which might alter their kinematics and kinetics and therefore increase the risk of musculoskeletal injuries. The purpose of this study was to investigate the biomechanical effects of additional weight on air assault soldiers performing landing tasks and the potential implication of the alterations on lower extremity musculoskeletal injuries, using the biomechanics model we previously developed.[16–19] This study focused specifically on the VGRF and knee kinematics during landing, which is a task that air assault soldiers frequently perform during combat activities, such as jumping out of a helicopter or a truck, and traversing uneven terrain or obstacles. On the basis of the 70 soldiers tested, we found greater maximum knee flexion, greater maximum VGRF, and prolonged time from initial contact to these two peak values with additional weight. We believe that specific strength training, proper landing skills, and properly increased exposure to weight carrying during physical training should be addressed to induce musculoskeletal adaptations that will likely reduce the risk of knee injuries in air assault soldiers.

The effects of additional weight carried by soldiers on knee kinematics and VGRF have several implications on training and injury prevention. First, the additional weight requires considerable lower extremity strength to land safely, especially at the knee, as the quadriceps must eccentrically contract to absorb and dissipate landing forces. Momentum is the product of the mass and the velocity of an object. Therefore, the kinetic influence of additional weight on soldiers' bodies and potentially landing kinematics is similar to landing without additional weight from a greater height or, equivalently, with additional weight at greater velocity. Maximum knee flexion angles,[27] as well as the range of knee flexion,[27,28] increases with drop landings from a raised platform height. A simulated parachute landing study demonstrated greater maximum knee flexion, greater range of knee flexion, and longer time to maximum knee flexion when participants dropped from a higher

TABLE I. Comparisons of Knee Joint Angles, Vertical Ground Reaction Forces, and T imings Between Non-IBA and IBA Conditions

	Right Leg			Left Leg		
	Condition			Condition		
	Non-IBA	IBA	*p* value	Non-IBA	IBA	*p* value
Knee Flexion Angle at Initial Contact (°)	10.5 ± 5.6	10.4 ± 5.5	0.905	12.5 ± 6.2	11.8 ± 6.5	0.107
Knee Valgus/Varus Angle at Initial Contact (°) (Positive = Valgus, Negative = Varus)	0.0 ± 10.1	−1.0 ± 11.8	0.466	−2.9 ± 13.8	−3.7 ± 14.8	0.566
Maximum Knee Flexion Angle (°)	76.2 ± 17.6	82.2 ± 14.4	<0.001	77.6 ± 18.8	84.4 ± 16.4	<0.001
Time to Maximum Knee Flexion Angle (ms)	239 ± 88	298 ± 73	<0.001	240 ± 102	292 ± 76	<0.001
Maximum Vertical Ground Reaction Force (Percent Body Weight)	371.2 ± 100.7	398.1 ± 94.3	0.002	330.5 ± 96.7	374.6 ± 88.2	<0.001
Time to Maximum Vertical Ground Reaction Force (ms)	37 ± 11	42 ± 9	<0.001	36 ± 12	40 ± 10	0.004

Statistical significance set at $p < 0.05$.

position.[29] During knee flexion, the knee extensors eccentrically contract to decelerate the body, and dissipate the impact, and absorb the energy transferred up from the ground.[28,30] As expected, our participants demonstrated increased maximum knee flexion and a longer time to reach maximum flexion with IBA; it naturally takes more knee angular displacement and time to stop the downward movement of the body with increased momentum. When such demand increases, a greater portion of the energy absorption shifts to the knee and hip extensors from the ankle muscles,[28,30,31] which have limited energy-dissipation capacity. The eccentric strength of knee extensors are considered a potential factor affecting maximum knee flexion during landing.[16] Although our participants demonstrated an appropriate adaptation of flexing the knees more, the additional weight added in the current study was only minimal and may not be reflective of actual carrying loads. As carry loads increase during tactical operations, the demand on muscular strength, especially eccentric strength at the knees and hips, would increase significantly to perform safe landings.

Second, proper landing techniques should be emphasized to address the increased VGRF and accompanied risk of injury. The vertical ground reaction force induces an external knee flexion torque. To counterbalance and control the knee flexion torque, there exists an internal knee extension torque (quadriceps activation), which simultaneously increases the ACL strain by producing an anterior shear force on the proximal tibia.[32] Our previous research has demonstrated that the greater the internal knee extension torque, the greater the proximal tibia anterior shear force.[19] Activation of the quadriceps, which increases anterior shear force by way of the patella tendon,[32] is also preactivated before initial contact.[29,33–35] Depending on the knee alignment at the instant of landing, the VGRF may increase the knee valgus torque, which can further increase ACL strain in the presence of anterior shear force at the knee.[36,37] Valgus alignment of the knee at landing has been considered a risk factor for noncontact ACL injury.[15] In addition to landing with greater knee valgus, those individuals at greater risk for injury experience greater proximal tibia anterior shear force during landing even when their vertical and posterior ground reaction forces are not significantly higher than those at less risk for noncontact ACL injury.[18] Although our participants did not show any sign of more dangerous knee alignment in the frontal plane with additional weight, the increased maximum VGRF they experienced has been linked to increased risk of noncontact ACL injuries.[15]

In the current study, an average of 18% of additional weight increased the maximum VGRF by 35% BW on each leg (based on data derived from Table I); with the additional weight of weapons, ammunition, and other combat equipment, the maximum VGRF during landing is expected to increase dramatically in tactical operations. In a previous study, the vertical ground reaction forces increased from 256% BW to 474% BW as the height of the dropping platform rose from 32 cm to 103 cm (equivalent to an increased velocity from 2.5 m/s to 4.5 m/s).[28] Our 50-cm platform, equivalent to a 3.1 m/s velocity, yielded a comparable 355% BW maximum VGRF under the non-IBA condition and 391% BW under the IBA condition. A high mobility multipurpose wheeled vehicle (HMMWV), widely used by the U.S. Army, has a deck height of approximately 84 cm, and the height of a window or a wall and the depth of a ditch can be close to a meter or more. Moreover, the maximum VGRF experienced during landing tasks performed in the field could be much greater than the standardized drop landing task performed indoors. A simulated parachute landing yielded 930% BW (9.3 times body weight) and 1,310% BW (13.1 times body weight) of maximum VGRF at vertical velocities of 3.3 and 4.5 m/s, respectively.[29] Such high VGRF was very close to the greatest value ever documented, in a single-leg double back somersault landing (1,440% BW).[38] The exact reason for such a large increase in maximum VGRF between tasks is difficult to determine; however, performing such a task is more dynamic, and has much higher uncertainty and unpredictability than a well-controlled standardized task. During tactical operations soldiers will quickly react to the environment and operation conditions and may not have time to prepare for the landing. In such context, soldiers may not be able to use their full capacity to reduce the impact. Thus, we would expect an even higher maximum VGRF that the air assault soldiers would encounter frequently in the battlefield.

One technique to reduce the VGRF is to increase the knee flexion angle at initial contact, and allow greater knee flexion throughout the landing.[28,30] Females, who are more vulnerable to noncontact knee injuries, demonstrate lower knee flexion angles at initial contact during two- legged landing,[14,27] although a limited amount of research has shown no gender differences[39] or increased knee flexion in females.[34] With less knee flexion, less energy can be absorbed, and more energy is transferred to the knees and hips from the ankles. We hypothesized that the knee flexion angles at initial contact would be greater under the IBA condition, assuming the additional weight would lead to a more cautious move. However, our participants demonstrated no statistical difference between conditions. We do not have sufficient information to conclude whether soldiers would land with a more extended knee when additional weight is carried on the basis of the current study and research design. Although the effect of additional weight was similar to increased dropping velocity in many ways, we also do not have a clear answer as to how a greater velocity would affect the knee flexion angle at initial contact. Huston et al.[27] found that knee flexion angle increased with increasing velocity during two-legged drop landings. In contrast, a more extended knee with greater velocity was observed in simulated parachute landing, which may explain the concurrent high maximum VGRF observed.[29] Although the task Huston et al.[27] used was more comparable to ours, the results from the simulated parachute landing may be more valuable to our research purposes. We cannot rule out the possibility that soldiers would land with more extended knees performing tactical operations in the field with additional weight.

In this study, we demonstrated the effect of additional weight on knee kinematics and VGRF of soldiers performing a two-legged drop landing task. These effects may increase the risk of lower extremity musculoskeletal injuries during a similar landing task; however, landing is not the only task that the additional weight could affect, and the knee is not the only joint subjected to increased risk of injury under the increased stress because of the additional weight. Military load carriage can also increase the ground reaction forces during walking,[40] alter pelvic and hip angles during standing,[41] and decrease balance and postural stability.[42] Craniovertebral angle and femur range of motion,[43] thoracic and lumbar spinal curvature,[24] forces suffered at the upper and lower back,[23] and trunk muscle activation patterns[41] can all be adversely affected by additional weight. Alterations in physiological performance, such as increased oxygen consumption, heart rate, ventilation, perceived exertion, and decreased knee muscle extension torque output were all evident in a simulated marching test with increased carried weight, suggesting the fatiguing effects of the heightened demands of additional load.[22,44] Our preliminary data from another study has also demonstrated similar effects with additional load (body armor and helmet = 18.6 kg). The addition of the body armor and helmet increased the peak VGRF during gait by 18.7% BW and the time to exhaustion during a VO2 max test decreased by 50% and caloric expenditure increased by 20%. Considering the trend of increasing weight carried by soldiers throughout history,[20] the effects of this weight on soldiers' performance and safety in tactical operations is an ongoing concern for soldiers' effectiveness and safety.

Because additional weight considerably increases the mechanical and physiological demands and potentially contributes to musculoskeletal injuries, integrating additional weight into soldiers' regular physical training seems prudent. Soldiers build their strength through their daily Army physical training and sharpen their combat skills through regular tactical training. However, soldiers frequently wear only fitness clothing and running shoes during physical training. Additional weight may be worn during tactical training, yet a progressive program to induce adaptations has not been implemented. On the other hand, during their deployment, soldiers are equipped with additional weight sometimes significantly more than encountered in previous physical and tactical training. The inconsistent exposure to additional weight during training may not induce the musculoskeletal demands to allow soldiers to build and maintain sufficient strength and develop adequate kinematic adaptations to meet the combat mission tasks. Increased integration of additional weight into physical training that simulates the demand of their tactical operations is therefore encouraged, as it may reduce the risk of injuries and promote soldiers' combat readiness.

We acknowledge this study has several limitations. First, we had to use 2D projection angles instead of 3D joint angles because of marker placement issues. Knee flexion and knee valgus angles can affect each other when the values are large. However, we only assessed knee valgus angle at initial contact, while knee flexion angles were small. And the knee valgus angle was low throughout the landing task and would have limited effect on the knee flexion angles. Second, the order of the two testing conditions was not randomized. A learning effect could have influenced the measurements during the IBA condition because it always followed the non-IBA condition. In an attempt to address this issue, we provided at least three practice trials for each condition and allowed more practice until participants felt comfortable and prepared. We believe participants could familiarize themselves with the landing tasks through practice, and therefore the order of the two testing conditions would not provide further alteration of performance. We also felt this order of testing was a safer protocol. Third, the current study did not include ankle kinematic calculations. Lephart et al.[16] suspected that ankle kinematics may affect the VGRF of landing tasks. Future studies investigating how the ankles would respond with increasing mechanical demands could provide additional insight of military injury prevention, particularly given the rate of ankle injury.

CONCLUSION

Even the minimum additional weight soldiers carry such as the addition of body armor, helmet, and a rifle, causes altered kinematics and ground reaction forces. These alterations attributed to carrying additional weight may increase the risk of knee and other lower body injuries. Gradually integrating additional weight, such as body armor, into the soldiers' physical training is recommended to promote kinematic adaptations and safer performance during landing tasks.

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Warrior Model for Human Performance and Injury Prevention: Eagle Tactical Athlete Program (ETAP) Part I

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Abstract

Introduction: Physical training for United States military personnel requires a combination of injury prevention and performance optimization to counter unintentional musculoskeletal injuries and maximize warrior capabilities. Determining the most effective activities and tasks to meet these goals requires a systematic, research-based approach that is population specific based on the tasks and demands of the warrior. **Objective**: We have modified the traditional approach to injury prevention to implement a comprehensive injury prevention and performance optimization research program with the 101st Airborne Division (Air Assault) at Ft. Campbell, KY. This is Part I of two papers that presents the research conducted during the first three steps of the program and includes *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. **Methods**: Injury surveillance based on a self-report of injuries was collected on all Soldiers participating in the study. Field-based analyses of the tasks and demands of Soldiers performing typical tasks of 101st Soldiers were performed to develop 101st-specific laboratory testing and to assist with the design of the intervention (Eagle Tactical Athlete Program (ETAP)). Laboratory testing of musculoskeletal, biomechanical, physiological, and nutritional characteristics was performed on Soldiers and benchmarked to triathletes to determine predictors of injury and optimal performance and to assist with the design of ETAP. **Results**: Injury surveillance demonstrated that Soldiers of the 101st are at risk for a wide range of preventable unintentional musculoskeletal injuries during physical training, tactical training, and recreational/sports activities. The field-based analyses provided quantitative data and qualitative information essential to guiding 101st specific laboratory testing and intervention design. Overall the laboratory testing revealed that Soldiers of the 101st would benefit from targeted physical training to meet the specific demands of their job and that sub-groups of Soldiers would benefit from targeted injury prevention activities. **Conclusions**: The first three steps of the injury prevention and performance research program revealed that Soldiers of the 101st suffer preventable musculoskeletal injuries, have unique physical demands, and would benefit from targeted training to improve performance and prevent injury.

Introduction

Unintentional musculoskeletal injury is a persistent and principal health concern for the United States military. Recent epidemiological evidence indicates that 19.5% of troops currently deployed to Iraq and Afghanistan report at least one nonbattle injury with 84.8% of individuals (of the 19.5%) seeking medical attention.[1] Many of these injuries are potentially preventable as 57% involved Sports/Athletics or Heavy Gear/Lifting. Earlier epidemiological studies demonstrate similar findings. In 1992, 31% of all U.S. Army hospitalizations were due to musculoskeletal conditions and injuries.[2] This percentage of musculoskeletal injuries remains high in the current conflicts.[3] The majority of these injuries were non-combat related[4] musculoskeletal injuries[5-8] and typically occurred during physical training, sports, and recreational activities. The Armed Forces Epidemiological Board has indicated that musculoskeletal injuries have a greater impact on health and readiness than medical complaints during peacetime and combat.[9] Furthermore, musculoskeletal injuries are a leading cause of hospitalization;[2] account for a large number of disability reviews;[7, 10] account for a significant amount of lost duty time;[11, 12] cost nearly one billion dollars yearly in care;[9, 10, 13] result in both short term and long term disability; and place a substantial burden on the medical system.[14] Although there are a number of identified predictors for unintentional musculoskeletal injuries (age, gender, anatomy, physical activity and fitness, flexibility, smoking, absolute amount of training, type of training, and acceleration of training),[14] they persist as a significant health concern facing servicemen and women and the individuals who care for and command them. Additional research is necessary to identify the modifiable neuromuscular, biomechanical, physiological, and musculoskeletal characteristics that predict injury.

Musculoskeletal injuries are potentially preventable with scientifically driven, culturally-specific, and population-specfic physical training programs. Typically, injury prevention research targets one specific injury, one joint, or one extremity, but injury prevention in the military must be more comprehensive in order to address the most common injuries across multiple joints and all extremities. But, injury prevention alone is only one aspect of a comprehensive physical training program. A successful program will also address physical performance and nutritional needs. Providing nutrients and fluid in the right combination to meet the unique demands of military training and missions will help fuel the muscle demands, allow for optimal adaptation, reduce fatigue and injury, and optimize physical performance. All three components (injury prevention, performance optimization, and nutritional repletion) must be specific to the Soldier based on the specific tasks he has to perform as well as the physical demands placed on him. Addressing specificity is based on a process that we refer to as *Task and Demand Analysis* (Figure 1) and it is part of our approach to injury prevention and performance optimization.

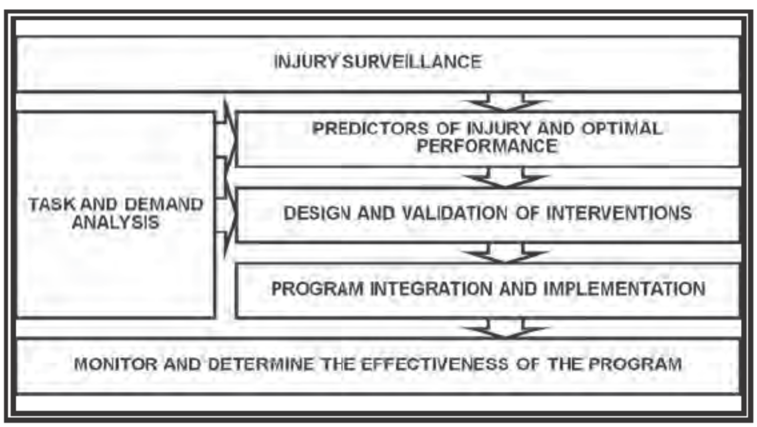

Figure 1: *University of Pittsburgh Injury Prevention and Performance Optimization Model*

Our approach is based on a conventional public health model of injury prevention and control[15-17] adapted to also include performance and nutrition interventions (Figure 1). Our model incorporates multiple research designs utilizing sound scientific methods to establish the following:

1. Scope and magnitude of musculoskeletal injuries through *Injury Surveillance*
2. Methodological and intervention specificity to meet the demands of distinct groups of service men who have to perform different tasks that have unique physical and physiological demands with *Task and Demand Analysis*
3. Modifiable neuromuscular, biomechanical, physiological, musculoskeletal, and nutritional characteristics that are *Predictors of Injury and Optimal Performance*
4. Effective training and education programs through the *Design and Validation of Interventions* that modify risk factors for injury and predictors of optimal performance
5. Appropriate procedures for *Program Integration and Implementation*
6. Capabilities of the intervention to reduce the incidence of unintentional musculoskeletal injury and optimize performance as we *Monitor and Determine the Effectiveness of the Program*

Currently, the University of Pittsburgh and the 101st Airborne Division (Air Assault) have established the Human Performance Research Center at Ft. Campbell, KY. The overall purpose of this collaboration is to create a systematic, data driven, and sustained injury prevention and performance optimization program to reduce the risk of unintentional, musculoskeletal injuries and improve physical performance in 101st Airborne/Air Assault Soldiers. Specifically, we are customizing our injury prevention and performance optimization model for application to a specific population of Soldiers.

The first step of the model is *Injury Surveillance*. Data are collected on the target population to understand the magnitude, nature and impact of the injury problem. Data includes the type of injuries (anatomical location, tissues involved, acute, overuse), where injuries occur, activity performed when injury occurred (physical training, tactical operations, for example), and the mechanism of injury. Data are collected utilizing self-report surveys or through queries of existing medical databases.

Task and Demand Analysis is critical component and a hallmark of our model. It provides a means by which the entire injury prevention and performance research model can be implemented within different populations of athletes or Soldiers. Data are collected in the field (physical training and tactical training) an includes both qualitative and quantitative examination of the tasks during which injuries typically occur, examination of the musculoskeletal and biomechanical qualities necessary for efficient and safe functional performance, and the physiological demands of the individual while performing his or her functional tasks. Typically these are single-case descriptive studies. *Task and Demand Analysis* data are incorporated into the identification of predictors of injury and performance as well as the design and validation of intervention programs.

The collection of *Predictors of Injury and Optimal Performance* is the next step and includes collection of subject-specific neuromuscular, biomechanical, physiological, musculoskeletal, and nutritional characteristics. Testing methodology must include task-specific biomechanical analyses as well as musculoskeletal and physiological protocols based on the demands of the target population (see *Task and Demand Analysis* above). The goal is to identify modifiable factors that predict injury and performance that can be targeted with intervention programs. Prospective studies are the most powerful research design to examine these factors. Descriptive and comparative studies can also be utilized to a lesser extent to narrow down and identify potential predictors of injury and performance.

Design and Validation of Interventions are population specific and based on the modifiable injury and performance predictors identified in the previous step. The design of the program must include the specific task and demands (see *Task and Demand Analysis* above) of the target population and can utilize population-specific data (descriptive/comparative studies) and previously identified predictors (existing peer-reviewed literature). Design must consider the environment, venue, and the logistical needs of the population (delivery and integration). The validation of the intervention is focused on the capability of the program to modify the identified predictors of injury and performance and is typically tested through randomized, controlled, clinical trials.

The next step in the model is *Program Integration and Implementation* and requires careful logistical planning and cooperation in order to deliver the intervention to the target population within their environment while accounting for the necessary procedures, training, and logistical concerns necessary for full integration. Data collection can include audits of participation and adherence to the program as well as clinical trials to test the efficacy of in the field deployment.

The final goal of the intervention is to reduce injury and improve performance. This is performed in the final step, *Monitor and Determine Effectiveness of the Program*. Long term injury tracking (similar to the first step) is performed on populations that have been exposed to the intervention and on populations who serve as the control group. Randomized, controlled, clinical trials are employed to examine the effectiveness of the program to reduce injury. Longitudinal studies are conducted on other variables of performance to examine the impact of the intervention on performance.

The purpose of the first of two companion papers is to describe the methodology and research results through the first three steps of our injury prevention and performance model (*Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*) as it is implemented and integrated within the 101st Airborne Division (Air Assault). Although this model is currently being applied to the 101st Airborne Division (Air Assault), by design it can be applied to different populations including Special Operations Forces where it may be more relevant due to the elite athlete benchmarking and the capability to individualize it to the specific needs of each Operator. Epidemiology data will be presented based on the self-reports of Soldiers tested in the Human Performance Research Center at Ft. Campbell, KY. An overview and example of a *Task and Demand Analysis* will be provided. Descriptive data across all testing methodologies (biomechanical, neuromuscular, musculoskeletal, and physiological) will be presented and will include profiling against elite athletes. Although nutrition data has been collected, it will not be reported in these two papers. The second paper will describe the methodology and research results for the *Design and Validation of Interventions*, *Program Integration and Implementation*, and *Monitor and Determine the Effectiveness of the Program*.

METHODS

Subjects

Two groups of subjects were enrolled in the study. The first group was composed of Soldiers from the 101st Airborne Division (Air Assault) in Ft. Campbell, KY. Demographic information is listed in Table 1. Soldiers were recruited via advertisement flyers and information sessions organized by the investigators of the study. A total of 404 Soldiers were tested (347 males and 57 females) across 121 different Military Occupational Specialties and all Physical Demand Rating categories.[18] To be included the study, Soldiers had to be 18 to 45 years old without any medical or musculoskeletal conditions that precluded them from full active duty. The second group included triathletes triathletes (15 males and 9 females) recruited via advertisement flyers as a benchmark for comparison to the Soldiers and for identification of suboptimal characteristics. To be included in the triathlete group, all individuals had to be healthy and free of any current medical or musculoskeletal conditions that would prevent participation in any of testing procedures. All of the triathletes were age group qualifiers for the Ironman World Championships. Triathletes were selected for the comparison group based on their multidisciplinary training and recognition as those who would have optimized many musculoskeletal and physiological characteristics such as aerobic and anaerobic endurance. Both groups were subdivided based on gender and comparisons between groups were within gender only. Human subject protection for the current study was approved by the University of Pittsburgh, Dwight D. Eisenhower Army Medical Center, Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office. All aspects of the study were explained to each Soldier and triathlete prior to voluntary participation.

TABLE 1
Subject Demographics

	101st Airborne Division (Air Assault)		Triathletes	
	Males (n=347)	Females (n=57)	Males (n=15)	Females (n=9)
Age (yrs)	28.1±6.6	26.7±5.5	35.7±8.5	34.7±7.1
Height (cm)	69.7±2.8	64.8±2.5	70.8±4.2	64.7±2.0
Mass (kg)	183.6±27.6	142.9±21.8	164.3±21.2	121.0±10.2

Instrumentation

Injury Surveillance

Demographic, medical, nutrition and injury data were collected using the University of Pittsburgh Military Epidemiology Database (UPitt-Med). Laboratory data were imported into the UPitt-MED. All data in the UPitt-MED were de-identified upon entry.

Task and Demand Analysis

Typically the *Task and Demand Analysis* utilizes accelerometers (ZeroPoint Technology, Johannesburg, South Africa) to examine segmental acceleration at the tibia, L5, and C7; a portable metabolic unit (OxyCon Mobile, Viasys, Yorba Linda, CA) to examine oxygen consumption and gas exchange; a heart rate monitor (Polar USA, Lake Success, NY); and an in-shoe plantar pressure system (Novel GmbH, Munich, Germany) to measure detailed foot pressure. Not all of these instruments are used during each task and demand analysis as logistical, environmental, and operational restrictions force modifications to actual testing instrumentation.

Predictors of Injury and Optimal Performance

Flexibility measurements of the shoulders, hips, knees, and ankles were assessed with a standard goniometer or digital inclinometer (Saunders Group, Chaska, MN). Strength of the shoulders, hips, knees, and back was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY). Ankle strength was assessed with a hand held dynamometer (Lafayette Instrument Company, Lafayette, IN). Balance testing data were collected with a single force plate (Kistler 9286A, Amherst, NY) at a sampling frequency of 1200 Hz. A portable metabolic system (OxyCon Mobile, Viasys, Yorba Linda, CA) was used to assess oxygen consumption during a maximal oxygen uptake test. Blood lactate was assessed with a portable lactate analyzer (Arkray, Inc, Kyoto, Japan). A heart rate monitor (Polar USA, Lake Success, NY) was worn by the subject during testing. Anaerobic power was measured utilizing the Velotron cycling ergometer (RacerMate, Inc, Seattle, WA). Body composition was assessed with The Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA) through air displacement plethysmography. Raw coordinate data for the biomechanical analysis of lower extremity performance and functional testing was collected with the six high-speed cameras (Vicon, Centennial, CO). Ground reaction forces were measured using two Kistler force plates (Kistler Instrument Corp., Amherst, NY).

<u>Procedures</u>

All testing of Soldiers of the 101st was performed in the University of Pittsburgh Human Performance Research Center at Ft. Campbell, KY. Subjects who were part of the athlete comparison group were tested at the Neuromuscular Research Laboratory at the University of Pittsburgh (Pittsburgh, PA). Testing occurred over two days (approximately two hours each day) separated by approximately one week. After informed written consent was obtained, each subject was asked to provide a detailed medical history and a history of all musculoskeletal injuries. Subjects were also given a detailed diet history including a food frequency and 24 hour recall to be filled out prior to returning on the second day (data not reported in the current manuscript).

Injury Surveillance

A detailed self-report of injury was obtained from participants in the study. Operational definitions of data (anatomic location of injury, type of injury, activity when injury occurred, etc.) were discussed and defined in meetings of the research group prior to the initiation of the study, in order to ensure validity and consistency of data.

Task and Demand Analysis

A total of seven task and demand analyses were performed to examine different physical training, tactical training, and other functional tasks that Soldiers have to perform as part of their regular duties. The activities chosen were based on consultation with the Division Surgeon and Division Command. They included the following:

<u>Task Analysis</u>

1. Drop exit from a vehicle
2. Rope climb (up and down)
3. Loading and unloading equipment from a vehicle
4. Night training – landing from a jump with low light conditions

<u>Demand Analysis</u> (Obstacle Course)

1. Eagle First Responder Course
2. Air Assault O-Course
3. Joint Readiness Training Center activities

The results of these analyses were utilized to develop the procedures examining *Predictors of Injury and Optimal Performance* and the exercises and activities included in the *Design and Validation of Interventions* (See Companion Paper). Additional tasks were examined based on the potential for injury. Data were collected in the field. The actual data collection procedures and equipment utilized was dependent on the specific task, environmental conditions, and the capability to collect data with minimal interference to training and the Soldier. For sake of brevity, a description of two examples of *Task and Demand Analysis* are provided.

Qualitative observations (See Figure 2 for task analysis and Figure 3 for demand analysis) were collected on one Soldier exiting a vehicle (task analysis) and quantitative data was collected on one Soldier during the 101st Airborne Division (Air Assault) Obstacle Course (demand analysis). The qualitative observations included musculoskeletal, neuromuscular, and biomechanical demands and an examination of the movement patterns, forces, velocities, joint angles, and planes of motion which identifies the muscles and other parts of the body used to execute the specific joint and whole body actions. The O-course was designed to evaluate Soldiers' ability to negotiate and maneuver obstacles without fear of height. There are nine obstacles that include: "tough one"

Figure 2: *Task analysis – Field observation with laboratory simulated testing*


Figure 3: *Demand analysis – Field testing as observed on the O-Course*

(rope climb), incline wall, "low belly over" (jump onto beam, forward flip, and land on the ground), "confidence climb" (log/beam climb, walk across beam, climb down), six vaults, swing stop and jump on a rope, low belly crawl (not performed due to equipment considerations), high step over, and "weaver" (over and under beams suspended in the air). One male Soldier (Age: 20 years; Height: 68 inches; Weight: 161 pounds) was observed during the O-Course and outfitted with the portable metabolic equipment and the heart rate monitor. The Soldier was wearing his army combat uniform and boots. For the purpose of task and demand analysis, the Soldier was asked to complete the O-course twice with an 8 minute 45 second rest between each run. The data (VO_2) were monitored during the rest period until it returned to resting value prior to the beginning of the O-course. Data were collected for a total of 24 minutes and 15 seconds while the subject was engaged in the O-Course training.

Predictors of Injury and Optimal Performance

Passive shoulder, hip, and knee motion were measured passively using the methods described by Norkin and White.[19] Passive measurements included hip flexion and extension, knee flexion, and triplanar shoulder motion. Posterior shoulder tightness was measured in a supine position but was based on the description by Tyler et al.[20, 21] Hamstring flexibility was measured in supine using the active knee extension test.[22] Active dorsiflexion was measured with the knee straight as described by Norkin and White.[19] Torso flexibility was measured in a seated position utilizing the torso rotation attachment of Biodex Multi-Joint System 3 Pro based on a previous study.[23]

Bilateral shoulder internal/external rotation, hip abduction/adduction, knee flexion/extension, and torso rotation strength were assessed with the Biodex System III Multi-Joint Testing and Rehabilitation System (Biodex Medical Inc., Shirley, NY). All torque values were adjusted for gravity by the Biodex Advantage Software v.3.2 (Biodex Medical Inc., Shirley, NY) and calibrated according to the specifications outlined in the manufacturer's service manual. For each test, the subjects were provided details of the procedure, stabilized according to the manufacturer's guidelines, given three practice trials (three sub-maximal contractions (50% effort) followed by three maximal contractions) to ensure patient understanding and familiarity. A rest period of at least 60 degree/seconds was given prior to each strength test. Reciprocal concentric isokinetic shoulder internal/external, knee flexion/extension, and left/right torso rotation strength was tested at 60°/second (5 repetitions). Isometric hip abductor/adductor strength was tested in the side-lying, hip neutral position while they performed three, five-second alternating hip abduction and adduction isometric contractions. Ankle inversion/eversion strength was measured with a handheld dynamometer. All ankle strength tests were performed in a seated position based on traditional manual muscle strength testing hand placement. Three trials for each movement were collected and averaged.

Balance testing was assessed according to Goldie et al.,[24, 25] using a single force plate sampling at a frequency of 100Hz. Subjects performed three trials (10 seconds each) of a single-leg standing balance test (barefooted) for each leg under eyes open and eyes closed conditions. Subjects were asked to remain as still as possible with feet shoulder width apart and hands on hips.

Subjects performed an incremental ramped protocol to determine maximal oxygen consumption and lactate threshold. Subjects were fitted with the portable metabolic system and a heart rate monitor. The protocol consisted of a five-minute warm-up; an initial three-minute workload at 0% grade (starting speed for each Soldier was 70% of the two-mile run time during the Soldier's most recent Army Physical Fitness Test); and followed by an incline increase of 2.5% (grade) every three minutes while the speed remained constant.[26] Prior to each change in incline, a finger stick for a blood sample was taken to assess blood lactate levels. Subjects were instructed to continue running until exhaustion (defined as the inability to continue the test due to cardiovascular or peripheral inhibition). Heart rate and VO_2 were monitored continuously throughout the test. The specific variables analyzed included relative maximal oxygen uptake (VO_{2max}: ml/kg/min), heart rate max (HR_{max}) in beats per minute (bpm), respiratory exchange ratio (RER: VCO_2/VO_2), VO_2 at lactate threshold (ml/kg/min), percent of VO_{2max} at lactate threshold ($\%VO_{2max}$), heart rate at lactate threshold (bpm), and percent of heart rate max at lactate threshold ($\%HR_{max}$).

Anaerobic power and capacity were measured with an electromagnetic cycling ergometer utilizing the Wingate protocol (Racermate Inc, Seattle, WA). Proper seat and handlebar adjustments were made before the subject's feet were secured to the pedals, and a warm-up cycle at a self-selected cadence was initiated at 125 Watts. Subjects underwent a 50-second cycling protocol. After fifteen seconds of maintaining 100 RPM at 125 Watts, the participant was instructed to sprint and generate as much speed prior to the initiation of the normalized resistance. The participant continued to sprint and maintained as much speed as possible during the remainder of the 30s resistance duration. A standardized braking torque of 9% body weight was utilized for males and 7.5% body weight was utilized for females.[27,28] Anaerobic power was reported as the peak watts normalized to body weight produced during the first five seconds of the test, and anaerobic capacity was reported as the average watts normalized to body weight produced during the entire 30-seconds (W/kg).

The Bod Pod® Body Composition System (Life Measurement Instruments, Concord, CA) was used to measure body composition. The Bod Pod® utilizes air-displacement plethysmography to measure body volume and calculate body density. The system underwent a standard calibration utilizing a 50.683 L calibration cylinder, and an additional two-point calibration prior to each test. Subject wore spandex shorts and swim caps. Body volume was measured until two consistent measurements were achieved. Predicted lung volume and an appropriate densitometry equation were used to calculate percent body fat (%BF). The Bod Pod Body Composition System was utilized to calculate body mass and percent of fat and fat free mass.

A biomechanical analysis was performed while subjects performed an athletic task (stop jump task) and a functional landing task (drop landing task). Subjects were fitted with sixteen retro-reflective markers on anatomical land marks according to Vicon's Plug-in-Gait (Vicon, Centennial, CO). Subjects' height, mass, ankle width, knee width, and leg length were entered into the operating software (Nexus v1.3, Vicon, Centennial, CO) prior to collecting a static calibration trial with the participant standing in anatomical position. After completing the static calibration trial, participants were instructed to perform the stop jump task – a standing broad jump from a normalized distance of 40% of the participant's height followed immediately (after landing on the force plates) by a maximal effort vertical jump.[25] For the drop landing task, subjects were instructed to drop from a standardized height of 20 inches and land on the force plates. Although this height is less than that observed during the task analysis of exiting a vehicle, it was deemed the safest height appropriate for the large range of subjects tested in the current study. Additionally, the protective mechanisms studied in are the same regardless of height.

<u>Data Reduction</u>

Injury Surveillance

Self-reported data about injuries in study participants were entered into UPitt-MED by athletic trainers at the Ft. Campbell laboratory, in the presence of the study participant. The Pitt-MED is designed to facilitate an epidemiological analysis of the factors associated with performance, injuries, disabilities and tactical readiness. Tables in the database store data about physiological measures of strength, endurance, cardiovascular fitness; and musculoskeletal (strength, flexibility and balance), biomechanical, anthropometric and demographic data; in addition to the data related to medical events and injury. A detailed nutrition history was completed for each subject including a 24 hour diet recall, food frequency questionnaire and dietary supplement survey (not reported in the current manuscript).

Task and Demand Analysis

Quantitative variables calculated for the specific *Task and Demand Analysis* performed and presented in the current manuscript included the minimum, maximum, and average heart rate; breathing frequency; oxygen consumption; and respiratory exchange ratio. Time spent exercising at or above the anaerobic threshold was estimated using laboratory determined VO_2 and lactate threshold data. A description of the tasks performed including the perceived musculoskeletal, neuromuscular, and biomechanical demands is presented as part of the qualitative analysis.

Predictors of Injury and Optimal Performance

All flexibility and range of motion measures are presented as an average of three trials. Strength measures are reported as an average of three trials and then normalized to each subject's individual body weight (tests using the Biodex System III Multi-Joint Testing and Rehabilitation System) or mass (hand held dynamometer). The standard deviation for the ground reaction forces for each direction (anterior-posterior, medial-lateral, and vertical) was calculated during the 10-second trial and then averaged across all three trials for both balance testing conditions.

For the aerobic test, a maximal test was verified by identifying one of the following physiological achievements: HR at or above age predicted max (220 – age), absolute oxygen uptake values not rising despite increase in intensity, blood lactate at or above 8mmol/L, respiratory exchange ratio (RER)

TABLE 2
Number of Injuries per Subject

Number of Injuries	Number of Subjects	Relative Frequency (%)
0	174	72.2
1	45	18.7
2	17	7.1
3	2	0.8
4	2	0.8
6	1	0.4
Total subjects	241	100.00%

at or above 1.1, or volitional fatigue. The metabolic data were filtered with a 15-second moving window to reduce the overall breath-by-breath data points. The VO_2 data were then plotted across time to identify the highest consecutive values over the time period of one minute during the test. Lactate values for each stage were plotted across time to identify lactate threshold. An inflection point was identified in the lactate plot as the point at which levels began rising greater than or equal to 1mmol/L between stages. The oxygen uptake and heart rate data points corresponding with the point in time of the lactate inflection point were used to calculate percent of VO_{2max} and HR_{max} at lactate threshold. Anaerobic power, anaerobic capacity, and fatigue index are automatically generated by the Wingate software upon completion of the test. Anaerobic power output is calculated as the peak within five seconds of the test starting while anaerobic capacity is calculated as the mean power output of the 30s duration. Anaerobic power and capacity are reported as relative (W/kg) variables. Fatigue index is calculated as the average rate of change in power across the 30s test. Body composition is reported in percent body fat mass based on total body volume utilizing the subject's body mass and race/gender appropriate density formulas.

TABLE 3
Anatomic Sub-Location of the Injuries

Anatomic Location	Sub-Location	Number of Injuries	Percent of Injuries
Lower Extremity	Foot and Toes	10	10.1
	Thigh	8	8.1
	Lower Leg	12	12.1
	Hip	1	1.0
	Knee	13	13.1
	Ankle	18	18.2
Upper Extremity	Hand and Fingers	3	3.0
	Upper Arm	2	2.0
	Shoulder	11	11.1
	Wrist	4	4.0
Spine	Cervical	1	1.0
	Thoracic	1	1.0
	Lumbopelvic	7	7.1
	Other	3	3.0
Head/Face		5	5.1
Total		99	99.9%*

*Percents do not add up to 100.0 due to rounding

TABLE 4
Types of Injuries

Type of injury		Number of injuries	Percent of injuries
Concussion		4	4.0
Ear injury		1	1.0
Fracture	Upper Extremity	2	2.0
	Lower Extremity	3	3.0
Sprain	Upper Extremity	6	6.1
	Lower Extremity	16	16.2
Strain	Spine	5	5.1
	Upper Extremity	4	4.0
	Lower Extremity	7	7.1
Dislocation – Lower extremity		1	1.0
Chondromalacia/Patellofemoral Pain		4	4.0
ITB		6	6.1
Plantar Fasciitis		7	7.1
Back pain/spasm		2	2.0
Other pain		2	2.0
Tendonitis - Lower Extremity		2	2.0
Nerve injury – Upper extremity		1	1.0
Shin Splints		3	3.0
Disc injury		1	1.0
Contusion		2	2.0
Subluxation – Lower extremity		1	1.0
Reported "overuse"		1	1.0
Shoulder separation		1	1.0
Meniscal		3	3.0
Shoulder Impingement		2	2.0
Unspecified injury type		9	9.1
Others		3	3.0
Total		99	99.8%*

*Percents do not add up to 100.0 due to rounding

Data processing for the biomechanical analysis of the two different lower extremity tasks has been reported elsewhere.[30] The variables analyzed for both tasks included the maximum knee and hip flexion angle; knee and hip flexion at initial contact; the maximum knee valgus/varus angle; the knee valgus/varus angle at initial contact; and the peak vertical ground reaction force.

Statistical Analysis

All data analysis was performed with de-identified data. The description of *Injury Surveillance* data included a calculation of the average number of injuries per person; relative frequencies of injuries by anatomic location; cause of injury; activity when injury occurred; and type of injury. The minimum, maximum, and average for each of the variables collected during the *Task and Demand Analysis* are presented in table format for each portion of the activity analyzed. The qualitative description of the task relative to the biomechanical and musculoskeletal demands is presented. Means and standard deviations for each of the *Predictors of Injury and Optimal Performance* collected are calculated for each group (Soldiers and triathletes) within gender. Comparisons between the Soldier group and triathlete group were performed within gender utilizing independent t-tests with an alpha level of 0.05 chosen a priori. Statistical analysis was done using SPSS 17.0 (SPSS Inc., Chicago IL).

Results

Injury Surveillance

Self-reported injury data for the one year prior to testing was available for 241 Soldiers. There were 13 bilateral injuries, which have been counted twice in this report. A total of 99 injuries were reported. One hundred seventy-four subjects (174/241, 72.2%) did not report any injuries during a one year period. The average numbers of injuries reported per subject during a one year period were 0.41. Forty-five Army personnel (45/241, 18.7%) had reported one injury, and seventeen (17/241, 7.1%) had reported two injuries, during a one year period (see Table 2). Figure 4 provides an overview of the general anatomic location for each of the injuries with a more specific breakdown presented in Table 3. The majority of injuries (62.6%) occurred in the lower extremity. The ankle joint (18.2%) and

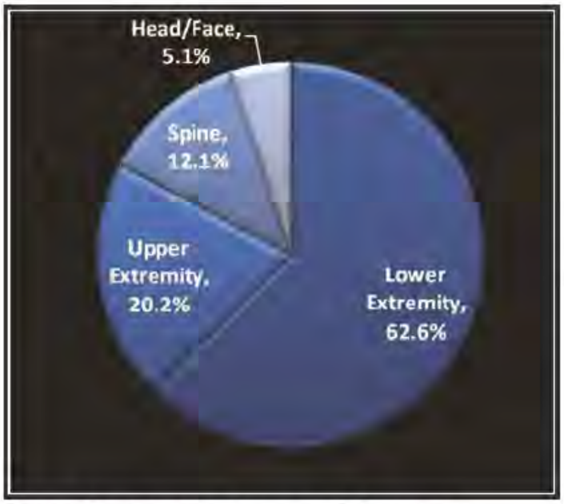

Figure 4: *Anatomic location of the injuries*

TABLE 5
Cause of Injuries

Cause of injury	Number of injuries	Percent of injuries
Running	34	34.3
Fall	8	8.1
Direct Trauma	8	8.1
Lifting	8	8.1
Landing	4	4
Twist/Turn/Slip (no fall)	2	2
Marching	2	2
Pulling	2	2
Cutting	1	1
Planting	1	1
Other	3	3
Not specified	15	15.2
Recreational activity/ sports related (cause not specified)	9	9.1
Training related (cause not specified)	2	2
Total	99	99.9%*

*Percents do not add up to 100% due to rounding

knee joint (13.1%) were the two most commonly injured joints. The most common specified type of injury (see Table 4) was a sprain of the lower extremity (16.2%), followed by strains of the lower extremity and plantar fasciitis (7.1% each). Ankle sprain was the most common injury, followed by plantar fasciitis, and then strain of the spine. The cause of injuries is presented in Table 5. Running was the most common cause of injury (34.3%). Recreational activity/sports related causes were the second most common cause (9.1%). Nearly half of all the injuries (48.5%) occurred during training (physical training, tactical training or unspecified training), and 15.2% of injuries occurred during recreational activity/sports activity. Some other activities during injury included combat (6.1%) and motor vehicular accident (4.0%). Activity during injury was not reported in 14.1% of injuries.(Figure 5).

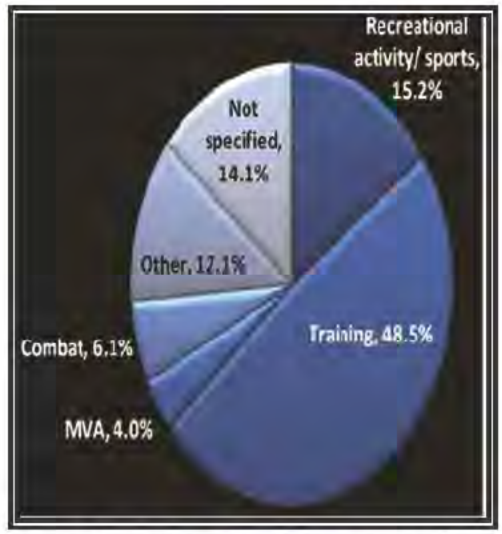

Figure 5: *Activity when injury occurred*

Task and Demand Analysis

Task Analysis

The following are the qualitative observations of exiting a vehicle. The task involves both a vertical and horizontal component. The vertical component involves the displacement of the body caused by gravity. As the Soldier drops off of the tailgate, from an approximate tailgate height of 1m, gravity accelerates him down to the ground. The Soldier's landing would exert a considerable amount of force to stop the vertical movement of his body. During the landing the Soldier flexes his hip and knee to reduce the impact caused by the vertical force. Additional load (equipment carried) would increase the magnitude of the force during landing. The horizontal component of this task requires the Soldier to neutralize his horizontal momentum and regain balance. During the landing the ground exerted a posterior force which would have to be neutralized by dynamic joint restraints.

Demand Analysis

The purpose of the demand analysis was to measure and characterize the metabolic and physiologic demands of specific military tasks including, energy expenditure, aerobic and anaerobic energy system usage and substrate utilization. Data from the laboratory maximal oxygen consumption test were utilized to evaluate the metabolic and physiologic responses of the O-Course training (Table 6). The O-Course training lasted 24 minutes and 15 seconds including an eight minute and 45 second rest between runs. The data revealed the O-course is a high intensity activity (Table 7). Of the 15 minutes and 30 seconds total O-Course run time, ~196kcals were expended, or ~12kcal per minute (10 METs). The Soldier completed the first run in six minutes and 35 seconds, of which approximately four minutes, or ~62%, was spent at or above anaerobic threshold. The second run was completed in eight minutes and 55 seconds, of which approximately one minute, or ~11%, was spent at or above anaerobic threshold. Of the total O-Course run time (15:30), approximately five minutes (32% of total time) involved training at or above the anaerobic threshold (laboratory determined lactate threshold) and five minutes and 30 seconds

(35% of total run time) involved training at or above 60% laboratory determined VO2max, but less than the lactate threshold, indicating high metabolic demands during the O-course training for both aerobic and anaerobic energy pathways (Figure 6). Heart rate averaged 173.6 beats per minute (87% HRmax) and peaked at 195.6 beats per min (98% HRmax) during the first run, and averaged 181.8 beats per minute (91% HRmax) and peaked at 197.6 beats per minute (99%HRmax) during the second run. Thus improving performance in training tasks similar to those tasks performed in the O-course requires adapting and enhancing both energy systems to optimize physical performance.

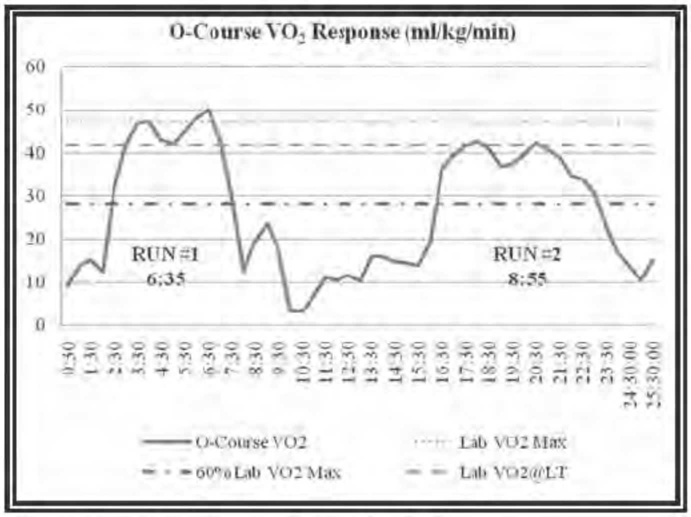

Figure 6: *VO2 response during the O-Course*

Predictors of Injury and Optimal Performance

The range of motion and flexibility data are presented in Table 8. A total of 24 comparisons were made between Soldiers and triathletes. Male Soldiers of the 101st demonstrated significantly greater right and left shoulder flexion; left shoulder extension; and right and left shoulder abduction than male triathletes. Male triathletes demonstrated significantly less posterior shoulder tightness for both the right and left shoulder as well as significantly greater right and left hip flexion. Male Soldiers of the 101st had significantly greater right and left hip extension and right and left calf flexibility. The comparisons between female Soldiers of the 101st and female triathletes revealed significant differences across nine of the flexibility and range of motion measures. Female 101st Soldiers had significantly greater right and left shoulder abduction but had more posterior shoulder tightness bilaterally than female triathletes. Female 101st Soldiers also had significantly greater knee flexion range of motion and calf flexibility. Right torso rotation was significantly greater in female triathletes compared to female 101st Soldiers.

TABLE 6
Laboratory Maximal Oxygen Uptake Data: O-Course Demand Subject (N=1)

VO_2Max* (ml/kg/min)	HR Max* (bpm)	RER Max* (VCO2/VO2)	VO_2 @ Lactate Threshold (ml/kg/min)	% VO_2 max at Lactate Threshold	Lactate at Lactate Threshold (mmol/L)
48.7	197.5	1.0	41.9	86.1	3.8

*Laboratory maximum values calculated by averaging the highest consecutive values over a one-minute period during the laboratory test.

Strength data are presented in Table 9. A total of 20 comparisons were made between Soldiers and triathletes. Male triathletes had significantly stronger left shoulder internal and external rotation; left knee flexion; and greater right knee flexion/extension strength ratio compared to male 101st Soldiers. Male 101st Soldiers had significantly stronger right and left ankle inversion and ankle eversion strength than male triathletes. Female triathletes had significantly stronger left shoulder internal rotation; right and left shoulder external rotation; right and left knee flexion; and left knee extension strength than female 101st Soldiers.

The balance data are presented in Table 10. Six comparisons were made for each of the two balance conditions tested (eyes open and eyes closed). The statistical analysis revealed only one significant difference between the 101st Soldiers and the triathletes, male 101st Soldiers had significantly lower (better) left leg medial/lateral ground reaction forces standard deviation (GRF SD) than male triathletes.

The physiology data is presented in Table 11. A total of 10 comparisons were made. Despite no significant difference observed in body mass index, male triathletes had significantly less body fat than male 101st Soldiers. Male triathletes also had greater mean anaerobic power, VO_{2max}, VO_2 at lactate threshold, and percent VO_2 at lactate threshold. Female triathletes had significantly lower body mass index and body fat percentage than female 101st Soldiers. Female triathletes also had significantly greater peak anaerobic power, mean anaerobic power, VO_{2max}, VO_2 at lactate threshold, percent VO_2 at lactate threshold, and heart rate at lactate threshold than female 101st Soldiers.

TABLE 7
Physiological Data During *O-Course Demand Analysis*

	TOTAL O-Course				Run #1 (6 min 35 sec)				Run #2 (8 min 55 sec)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Heart Rate (beats/min)	169.6	23.3	124.4	197.6	173.6	28.5	124.4	195.6	181.8	20.2	131.4	197.6
Breathing Frequency (breaths/min)	41.2	12.6	3.0	58.2	41.7	11.2	23.1	53.2	49.6	8.0	34.1	58.2
VO_2 (ml/kg/min)	26.7	14.4	3.2	50.1	34.4	15.8	9.1	50.1	32.8	10.1	13.5	42.8
Respiratory Exchange Ratio (VCO_2/VO_2)	0.9	0.1	0.7	1.2	0.9	0.1	0.8	1.0	0.9	0.1	0.9	1.1

The biomechanical data for the stop-jump task and the vertical drop landing task are presented in Table 12 and Table 13 respectively. A total of 12 comparisons were made for each task.

TABLE 8
Range of Motion and Flexibility (Degrees)

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Shoulder Flexion[a]	187.2	7.3	177.4	10.9	p<0.001	188.0	14.7	188.0	10.7	1.0000
Left Shoulder Flexion[a]	187.8	7.3	176.7	10.7	p<0.001	186.6	17.2	188.7	11.5	0.7315
Right Shoulder Extension	70.8	13.3	69.2	8.5	0.6448	83.6	9.8	80.4	8.4	0.3585
Left Shoulder Extension[a]	72.6	13.0	71.4	9.2	p<0.001	85.0	10.0	82.4	6.3	0.4540
Right Shoulder Abduction[a,b]	206.1	9.5	194.1	11.3	p<0.001	211.8	8.8	198.1	18.3	0.0024
Left Shoulder Abduction	205.4	10.3	193.0	10.0	p<0.001	209.7	6.9	201.4	10.8	0.0071
Right Shoulder External Rotation	109.9	13.2	111.8	7.1	0.5803	120.3	16.8	123.3	12.2	0.6095
Left Shoulder External Rotation	104.2	12.0	109.1	8.6	0.1190	113.9	14.9	117.5	13.6	0.4985
Right Shoulder Internal Rotation	58.5	10.6	54.3	9.1	0.1320	59.9	11.6	62.9	16.4	0.4991
Left Shoulder Internal Rotation	66.1	13.2	62.4	9.7	0.2843	66.0	14.8	74.9	13.6	0.0953
Right Shoulder Posterior Shoulder Tightness[a,b]	102.4	9.7	109.7	7.0	0.0043	108.7	7.5	121.2	10.8	p<0.001
Left Shoulder Posterior Shoulder Tightness[a,b]	104.4	9.4	110.9	7.6	0.0089	110.5	6.7	122.8	11.2	p<0.001
Right Knee Flexion[b]	143.1	6.6	141.5	6.9	0.3729	148.5	5.9	141.3	8.0	0.0046
Left Knee Flexion[b]	142.3	7.1	139.2	6.3	0.1051	147.5	5.9	141.4	7.2	0.0122
Right Active Knee Extension	18.8	9.4	14.5	11.4	0.0867	11.4	7.9	12.3	11.5	0.7671
Left Active Knee Extension	17.6	9.9	14.4	9.6	0.2208	9.6	7.3	12.6	11.6	0.2977
Right Hip Flexion[a]	133.1	7.1	138.2	5.7	0.0075	135.8	16.9	141.3	10.4	0.3590
Left Hip Flexion	133.4	7.2	136.8	5.7	0.0869	135.8	16.3	139.0	8.2	0.5736
Right Hip Extension[a]	29.3	8.0	21	8.5	p<0.001	33.9	7.3	35.5	9.4	0.5598
Left Hip Extension[a]	30.0	8.2	20.7	6.3	p<0.001	34.2	7.1	36.7	7.8	0.3368
Right Calf Flexibility[a,b]	15.9	6.8	12.0	5.9	0.0296	15.1	5.4	10.7	5.5	0.0268
Left Calf Flexibility[a,b]	16.1	6.8	11.7	5.6	0.0140	15.1	6.1	10.1	6.3	0.0262
Right Torso Rotation[b]	70.4	11.0	71.8	9.1	0.6276	72.7	11.5	81.6	12.0	0.0357
Left Torso Rotation	65.8	10.6	69.7	11.9	0.1662	68.3	11.5	75.9	11.1	0.0689

[a]Significant difference between male Soldiers and Triathletes

[b]Significant difference between female Soldiers and Triathletes

TABLE 9
Strength

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Shoulder Internal Rotation (%BW)	59.64	15.54	64.30	9.67	0.2455	36.28	8.45	40.83	8.83	0.1404
Left Shoulder Internal Rotation (%BW)[a,b]	54.65	15.94	65.52	13.56	0.0094	33.97	8.14	42.99	8.18	0.0030
Right Shoulder External Rotation (%BW)[b]	42.09	8.75	46.49	6.92	0.0570	29.94	5.14	34.89	6.71	0.0124
Left Shoulder External Rotation (%BW)[a,b]	37.94	7.82	44.48	7.26	0.0014	26.99	4.62	32.71	7.45	0.0025
Right Shoulder Internal/External Strength Ratio	0.73	0.14	0.73	0.10	1.0000	0.85	0.20	0.87	0.15	0.7752
Left Shoulder Internal/External Strength Ratio	0.72	0.15	0.69	0.11	0.4448	0.82	0.17	0.76	0.10	0.3084
Right Knee Flexion (%BW)[b]	114.81	27.14	128.00	22.63	0.0648	92.98	21.05	115.47	15.44	0.0032
Left Knee Flexion (%BW)[a,b]	111.72	26.34	128.50	23.23	0.0158	88.82	20.80	113.96	14.88	0.0009
Right Knee Extension (%BW)	236.12	48.03	242.09	50.38	0.6387	191.30	37.16	216.53	21.68	0.0525
Left Knee Extension (%BW)[b]	226.02	44.56	241.31	42.89	0.1938	178.18	38.19	211.38	34.71	0.0170
Right Knee Flexion/Extension Strength Ratio[a]	0.49	0.09	0.54	0.10	0.0369	0.49	0.06	0.53	0.04	0.0585
Left Knee Flexion/Extension Strength Ratio	0.50	0.09	0.53	0.05	0.2011	0.50	0.08	0.54	0.05	0.1519
Right Ankle Inversion Strength (%BW)[a,b]	34.43	7.22	23.60	3.72	p<0.001	24.90	6.70	19.18	2.23	0.0141
Left Ankle Inversion Strength (%BW)[a,b]	33.21	6.86	23.15	4.76	p<0.001	24.08	6.16	19.01	3.23	0.0190
Right Ankle Eversion Strength (%BW)[a,b]	30.49	6.71	21.52	2.34	p<0.001	22.25	5.93	16.96	1.58	0.0103
Left Ankle Eversion Strength (%BW)[a,b]	30.99	6.50	21.61	3.48	p<0.001	22.61	6.00	18.16	4.24	0.0365
Right Ankle Inversion/Eversion Strength Ratio	1.15	0.19	1.10	0.12	0.4199	1.13	0.21	1.13	0.11	1.0000
Left Ankle Inversion/Eversion Strength Ratio	1.09	0.18	1.08	0.20	0.8342	1.08	0.20	1.08	0.22	1.0000
Right Torso Rotation Strength (%BW)	145.12	33.05	151.51	25.94	0.4607	110.49	32.89	118.53	24.59	0.4858
Left Torso Rotation Strength (%BW)	144.82	32.80	154.57	30.90	0.2596	111.62	28.02	114.85	25.74	0.7466

[a]Significant difference between male Soldiers and Triathletes

[b]Significant difference between female Soldiers and Triathletes

TABLE 10 Balance (SD)										
	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Leg Eyes Open - Anterior/Posterior GRF	2.78	0.86	2.84	0.94	0.7938	2.02	0.55	2.32	1.22	0.2291
Left Leg Eyes Open - Anterior/Posterior GRF	2.79	1.01	3.26	1.06	0.1282	2.04	0.51	1.79	0.53	0.1828
Right Leg Eyes Open - Medial/Lateral GRF	3.44	1.16	3.88	1.52	0.1613	2.43	0.96	2.60	2.08	0.7068
Left Leg Eyes Open - Medial/Lateral GRF	3.43	1.46	4.09	1.54	0.0905	2.40	0.75	2.08	0.81	0.2481
Right Leg Eyes Open - Vertical GRF	4.65	2.19	5.26	2.14	0.2942	3.18	1.34	3.78	2.08	0.2618
Left Leg Eyes Open - Vertical GRF	4.77	2.74	5.87	2.79	0.1318	3.40	1.34	3.29	1.29	0.8203
Right Leg Eyes Closed - Anterior/Posterior GRF	6.44	2.66	6.84	2.14	0.5659	4.43	1.77	5.82	2.90	0.0552
Left Leg Eyes Closed - Anterior/Posterior GRF	6.76	3.40	7.59	4.16	0.3643	4.81	1.55	6.00	2.83	0.0699
Right Leg Eyes Closed - Medial/Lateral GRF	10.11	4.57	11.10	4.93	0.4169	6.15	2.39	7.59	6.28	0.2210
Left Leg Eyes Closed - Medial/Lateral GRF[a]	9.93	4.79	12.80	7.26	0.0295	6.98	2.41	7.92	6.40	0.4290
Right Leg Eyes Closed - Vertical GRF	14.53	12.22	13.82	6.37	0.8237	8.61	5.52	10.13	5.72	0.4517
Left Leg Eyes Closeed - Vertical GRF	14.75	11.94	18.88	14.53	0.1988	10.95	9.23	10.72	5.67	0.9428

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

TABLE 11 Physiology										
	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Body Mass Index (BMI)[b]	23.0	2.9	23.1	2.3	0.8953	23.96	3.09	20.33	0.97	p<0.001
Body Fat %[a,b]	20.1	7.5	12.3	4.4	p<0.001	26.72	5.70	17.37	4.38	p<0.001
Peak Anaerobic Power (Watts)[b]	13.3	2.1	13.8	1.0	0.3601	9.49	1.66	11.92	1.43	p<0.001
Mean Anaerobic Power (Watts)[a,b]	7.8	1.0	9.3	0.7	p<0.001	6.13	0.75	8.37	0.80	p<0.001
VO2 Max (mL/min/kg)[a,b]	47.5	7.6	69.8	7.3	p<0.001	40.29	5.37	61.15	5.44	p<0.001
VO2 at Lactate Threshold (mL/min/kg)[a,b]	39.0	7.0	58.2	7.3	p<0.001	33.52	5.49	54.03	5.91	p<0.001
VO2 % at Lactate Theshold	81.8	10.3	83.7	8.5	0.4826	82.16	13.97	88.38	6.57	0.1968
HR Max[b]	188.6	14.2	182.7	11.3	0.1139	188.89	9.59	179.89	11.41	0.0139
HR at Lactate Threshold	169.4	15.3	167.2	12.2	0.5837	171.40	12.09	168.44	13.33	0.5057
HR % at Lactate Threshold	89.6	7.2	91.5	3.9	0.3113	90.96	5.18	93.62	3.77	0.1465

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

For the stop-jump task, male triathletes landed with greater hip flexion at initial contact bilaterally; less left hip abduction at initial contact; and greater left knee flexion at initial contact than male 101st Soldiers. Male 101st Soldiers had greater maximum knee flexion angle bilaterally than male triathletes. There were only two significant differences between female 101st Soldiers and female triathletes during the stop-jump task. Female triathletes landed with significantly greater knee flexion at initial contact bilaterally than female 101st Soldiers. There were no observed significant differences for either gender during the vertical drop landing.

Discussion

The purpose of this paper (Part 1 of two companion papers) was to describe the methodology and research results related to the first three steps of our injury prevention and performance optimization model. These steps included *Injury Surveillance*, *Task and Demand Analysis*, and *Predictors of Injury and Optimal Performance*. Data was presented based on self-reported injury history; quality and quantitative analysis of tasks and activities that Soldiers have to perform as part of their duties; and on musculoskeletal, physiological, and biomechanical testing in the laboratory. The injury epidemiology data revealed a history of injury that is consistent with previous studies; injuries that are primarily occurring during physical and tactical training; and injuries that are potentially preventable through interventions. The qualitative and quantitative analysis of the task and demand analyses demonstrated that a biomechanical analysis of a vertical drop landing as well as anaerobic ca-

TABLE 12
Stop-Jump Task

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Hip Flexion at Initial Contact (Degrees)[a]	42.4	11.3	51.1	15.6	0.0049	45.9	11.7	49.6	11.7	0.3869
Left Hip Flexion at Initial Contact (Degrees)[a]	43.6	11.1	54.6	17.2	p<0.001	46.1	12.5	50.2	11.2	0.3628
Right Hip Abduction at Initial Contact (Degrees)	-3.7	4.1	-2.9	4.2	0.4637	-2.6	3.5	-2.6	3.9	1.0000
Left Hip Abduction at Initial Contact (Degrees)[a]	-3.7	4.0	-1.3	4.1	0.0248	-2.5	5.1	-5.0	3.0	0.1613
Right Knee Flexion at Initial Contct (Degrees)[b]	25.8	8.0	28.2	13.5	0.2813	26.8	7.7	33.7	7.8	0.0167
Left Knee Flexion at Initial Contct (Degrees)[a,b]	27.5	8.4	34.5	11.5	0.0024	27.4	8.2	34.9	8.2	0.0145
Right Knee Valgus/Varus at Initial Contact (Degrees)	4.6	6.3	5.9	5.3	0.4344	-1.4	5.6	-4.6	6.7	0.1318
Left Knee Valgus/Varus at Initial Contact (Degrees)	4.7	6.8	5.8	8.8	0.5498	-1.4	6.0	-2.6	3.7	0.5658
Right Knee Maximum Flexion (Degrees)[a]	92.0	14.0	77.7	18.0	p<0.001	89.4	13.4	89.6	9.6	0.9661
Left Knee Maximum Flexion (Degrees)[a]	92.1	13.9	81.6	11.1	0.0044	88.2	13.7	92.2	11.7	0.4151
Right Peak Vertical Ground Reaction Force (% BW)	205.3	56.3	208.4	47.2	0.8347	201.6	63.9	198.6	65.3	0.8978
Left Peak Vertical Ground Reaction Force (% BW)	195.7	54.3	221.3	62.0	0.0793	200.6	68.0	184.0	40.5	0.4828

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

pacity testing should be incorporated both in the methodology for examining *Predictors of Injury and Optimal Performance* and in the *Design and Validation of Interventions*. The laboratory testing revealed a number of significant differences across all testing categories (Range of Motion and Flexibility; Strength; Balance; Physiology; and Biomechanical variables) between the Soldiers of the 101st and the triathlete group used as comparison.

Injury Surveillance

The injury epidemiology collected on Soldiers of the 101st describes the magnitude, nature, scope, and impact of the injury problem and was the first step of our model, *Injury Surveillance*. Data was collected based on self-report surveys in which Soldiers were asked to describe the anatomical location and tissues involved in the injury; whether the injury was acute or chronic; where the injury occurred and during what activity; and what was the mechanism of injury. The results of the current study indicate the need for injury prevention measures to target common shoulder, knee, ankle, and back injuries that occur during physical and tactical training as well as sports and recreational activities. Our injury surveillance is consistent with previous, older studies that demonstrated the need for strategies and interventions to reduce unintentional musculoskeletal injury. Despite this historical evidence and efforts to mitigate unintentional musculoskeletal injury a significant need persists based on the results of the current study. All of the injuries reported in the current study are not preventable, but there are many instances where targeted intervention can successfully reduce injury (see Part II). The prevention of unintentional musculoskeletal injury also has an economic impact as each injury prevented results in a cost of care savings. Depending on the injury and the number of injuries prevented, the cost savings can be substantial and outweighs the cost associated with the prevention measures.[31]

Similar to previous studies, the results of this injury surveillance show that unintentional musculoskeletal injuries are very common. A total of 99 injuries were reported within the group of 241 Soldiers who participated in the injury sur-

TABLE 13
Vertical Drop Landing

	Males					Females				
	101st		Triathletes			101st		Triathletes		
	Mean	±SD	Mean	±SD	p-value	Mean	±SD	Mean	±SD	p-value
Right Hip Flexion at Initial Contact (Degrees)	19.4	7.3	22.7	8.6	0.0943	23.6	6.7	19.5	6.6	0.0958
Left Hip Flexion at Initial Contact (Degrees)	20.7	7.5	24.1	8.2	0.0916	23.6	7.2	19.7	6.6	0.1358
Right Hip Abduction at Initial Contact (Degrees)	-3.7	3.4	-2.1	4.0	0.0816	-2.7	4.0	-2.9	2.5	0.8857
Left Hip Abduction at Initial Contact (Degrees)	-3.8	3.3	-2.8	3.9	0.2614	-3.2	3.9	-2.5	2.2	0.6042
Right Knee Flexion at Initial Contct (Degrees)	17.9	6.1	20.3	8.6	0.1515	20.1	6.4	20.3	5.0	0.9296
Left Knee Flexion at Initial Contct (Degrees)	19.7	6.3	21.4	7.5	0.3174	20.9	5.8	21.7	4.4	0.6959
Right Knee Valgus/Varus at Initial Contact (Degrees)[b]	2.8	5.0	3.4	4.9	0.6522	-0.5	4.4	-4.0	3.8	0.0292
Left Knee Valgus/Varus at Initial Contact (Degrees)	2.8	5.2	1.9	4.5	0.5133	-1.4	4.2	-2.2	2.5	0.5834
Right Knee Maximum Flexion (Degrees)	86.7	18.9	82.9	16.9	0.4483	90.5	14.0	83.7	13.2	0.1817
Left Knee Maximum Flexion (Degrees)	87.6	18.6	83.2	15.9	0.3715	89.8	13.4	87.2	12.7	0.5915
Right Peak Vertical Ground Reaction Force (% BW)	365.3	98.4	332.5	112.9	0.2158	359.2	92.3	309.1	65.7	0.1258
Left Peak Vertical Ground Reaction Force (% BW)	336.1	98.6	312.3	117.8	0.3711	337.0	85.8	297.4	84.9	0.2070

[a]Significant difference between male Soldiers and Triathletes
[b]Significant difference between female Soldiers and Triathletes

veillance survey which represents 410 injuries per 1000 person-years. In a recent study, Hauret et al.[32] used military medical surveillance data to identify injury-related musculoskeletal conditions among non-deployed, active duty service members in the year 2006, and reported the rate of injuries to be 628 injuries per 1000 person-years, which is slightly more than the self-reported rate in our study subjects. There are important methodological differences between the current study and Hauret et al. It is likely that their method of counting could have led to injuries being counted twice if the servicemember sought medical attention more than once, with a gap of more than 60 days between encounters, as is likely to happen with chronic musculoskeletal conditions. The lower rate of injuries in our study may also be because the injuries in our study were self-reported, and some Soldiers may not have reported all injuries. Interestingly, in the case of the majority of injuries, our study subjects were engaged in training or recreational activity/sports at the time of injuries. Combat was responsible for a very small proportion of the injuries. This is similar to findings from previous studies[11, 33] as more casualties have been caused among U.S. troops by non-combat injuries and disease than by combat.[34] Injuries outside of theater can limit the ability to prepare and train for deployment while injuries within theater can reduce the capacity of the individual to participate in tactical missions.

In our study, sprains and strains made up 38.4% (38/99) of all injuries; of these sprains and strains 60.5% (23/38) affected the lower extremity. According to a review of medical and personnel data for non-deployed active duty personnel for 2000–2006 by Jones et al.,[35] sprains and strains were responsible for 48.8% of injury ambulatory visits. Of the total sprains and strains, 49.8% affected the lower extremity. Even though Jones et al. counted injury ambulatory visits and our study counted injuries, the finding from these two studies highlight the relative importance of sprains and strains of the lower extremity. The high numbers of military personnel who seek outpatient care for sprains and strains highlights the need for greater attention to the prevention of these and other common unintentional musculoskeletal injuries.

Even though unintentional musculoskeletal injuries are not life-threatening, they result in pain, morbidity, loss of duty time,[11,12] increased medical costs,[12] disability,[10] medical evacuation from theater,[36] and attrition from the military.[5] All of these previous scenarios can reduce the capability and capacity of the Soldier to train and prepare for deployment and/or tactical missions while in theater. It has been estimated that the medical discharge of one active duty U.S. military member in his or her twenties costs the government approximately $250,000 in lifetime disability costs, excluding health care costs.[37,38] In the year 2005, Cohen et al., estimated that the financial cost of medically boarding one Special Operations or some other highly trained Soldier and retraining a replacement can be more than U.S. $1,000,000.[39]

Epidemiology studies often rely on self-reported data.[40-42] The advantages of using self-report are time-efficiency, easy availability and cost-effectiveness. Also, self-reported injury history can be expected to include information about all injuries that have occurred in the past, whether or not medical care was sought, and even if care was sought from a healthcare professional outside the system from which medical records were obtained. This is expected to give a complete picture of the injury history. An important limitation of self-reported injuries is problems with recall, which increase as the time period between injury occurrence and the self-report increases.[43] In our study, difficulties with recall were minimized by including only those injuries that occurred one year prior to the date of survey. Other potential limitations of self-reported injuries are that Soldiers may not report all their injuries due to the culture of stoicism in the military, and the accuracy of self-reported injuries may be influenced by the level of health knowledge of the study subject. Army medical records are currently being examined and compared to self-reported history to determine validity and correspondence between these two sources of injury surveillance data.

Task and Demand Analysis

We modified the traditional approach to injury prevention and performance optimization to address different populations, different environments, and the different needs of the study population by adding *Task and Demand Analysis*. The goal of the *Task and Demand Analysis* is to determine the specific functional needs of the population to be examined. The information gathered in this step drives the specific methodology for examining *Predictors of Injury and Optimal Performance* and is also incorporated into *Design and Validation of Interventions*. These analyses are performed in the field and include qualitative and quantitative study of tasks that the specific population has to perform as part of their daily duties.

The task analysis described was based on exiting a vehicle and includes landing forces that can potentially increase joint loading forces. The vertical component of the landing forces (vertical ground reaction force) can increase joint loading significantly as these forces are transmitted up the lower extremity kinetic chain. The individual Soldier is at potential risk for injury if he or she is unable to efficiently absorb and distribute these forces.[44] The horizontal component which is typically measured as anterior-posterior ground reaction forces in a laboratory setting is a significant predictor of proximal anterior tibia shear force,[29] the most direct loading mechanism of the anterior cruciate ligament.[45, 46] Combined, these different forces place significant demands on the individual Soldier that require sufficient strength, efficient movement patterns, and appropriate timing/activation of the muscular restraints necessary for dynamic joint stability. These demands can be compounded when carrying additional load[30] and landing on unlevel terrain. The task analysis presented in the current manuscript was the driving factor for including a simulated landing (vertical drop landing) in the laboratory testing (see *Predictors of Injury and Optimal Performance*). The investigation of this task in a controlled laboratory environment provides insight into the kinematic and kinetic characteristics necessary for maintenance of dynamic joint stability.

During the O-Course training, physiological responses were calculated for each individual run, total run time, as well as the entire 24 minute training activity. The Solider studied expended 196 kcals (~10 kcals per minute) during the entire O-course training session which is equivalent to 10 METs, requiring energy similar to activities such as walking and carrying a 50-74 pound load upstairs, swimming freestyle vigorously or running six miles per hour.[47] The O-Course is a relatively high intensity activity, where approximately 67 % of the time was spent exercising greater than or equal to 60% of VO_{2max} (moderate to high intensity), of that 32% of time was spent at power outputs greater than or equal to the anaerobic threshold. The first run was completed at a high intensity (at or above the lactate threshold) for ~62% of the run; however, during the second run the ability to achieve and sustain a high intensity power output dropped to approximately ~11% and run time increased by 2 minutes and 20 seconds. Further, the subjects heart rate did not return to baseline between runs and both average and peak heart rate were higher during the second run. The performance decrement observed in the second run may be the result of inadequate adaptations of the aerobic energy system to buffer and clear lactate and to facilitate recovery during multiple bouts of high intensity exercise. Activities performed above the lactate threshold rely predominantly on anaerobic metabolism, including the phosphagen and glycolysis energy systems. These energy pathways utilized phosphocreatine and glucose (carbohydrate) exclusively to resupply ATP for muscle contraction. Training at intensities below the lactate threshold rely predominantly on aerobic metabolism and thus the remainder of time during the O-course the Soldier relied on a combination of carbohydrate and fat to supply to fuel muscle contraction. Thus, it appears that both anaerobic and aerobic energy systems are important for meeting the demands of the O-Course training. Knowing the metabolic and physiologic demands enables physical training programs and feeding strategies to be developed that adapt and fuel the muscles to optimally perform and expedite recovery between bouts of strenuous exercise. Additionally, all of the observations and measurements made across all of the task and demand analyses performed facilitated the design of both the methodology and protocols utilized in *Predictors of Injury and Optimal Performance* and the training strategies to be employed in the *Design and Validation of Intervention*. There are some limitations to this approach. First, the tasks analyzed must be specific to the population studied and specific to the tasks performed by the individuals within that population, otherwise these analyses may not applicable and their usefulness in protocol and intervention design would be diminished. Second, these analyses do not take into account the cognitive aspects of the tasks analyzed. Unfortunately, the analyses of the cognitive aspects of functional tasks do not provide the objective measures necessary to drive protocol and intervention development.

Predictors of Injury and Optimal Performance

The goal of the laboratory testing of Soldiers is to identify *Predictors of Injury and Optimal Performance*. The specific laboratory tests included in this study were based on the task and demand analyses performed on Soldiers of the 101st. The current study is a descriptive comparison of Soldiers of the 101st compared to triathletes. The data presented is part of a larger ongoing study in which each of the Soldiers are enrolled in a prospective study during which injuries will be tracked in order to match the neuromuscular, biomechanical, physiological, and nutritional characteristics to risk of injury. The comparisons performed in the current manuscript between Soldiers of the 101st and triathletes demonstrated numerous, significant differences across many of the testing variables. Although these comparisons are descriptive and retrospective in nature, they do reveal the need for a revision of current training regimes in order to prevent injury and optimize performance. Examples can be found for both injury prevention and performance optimization for both genders and across all of the testing areas (range of motion, flexibility, strength, balance, physiology, and biomechanics).

Range of motion (ROM) and flexibility has traditionally been the target of physical training programs in order to decrease the risk of injury. The comparisons between groups in the current study revealed significant differences across many of the variables. For some of the variables, the Soldiers of the 101st (both genders) demonstrated better ROM/flexibility than the triathletes, but there were a few instances where the Soldiers demonstrated decreased flexibility. For example, both genders within the 101st group demonstrated significantly higher (represented by lower scores) posterior shoulder tightness than the triathletes. Tightness of the posterior capsule of the shoulder has been implicated as a contributor to abnormal kinematics of the scapula and shoulder impingement.[48, 49] Correction of this tightness utilizing stretching and mobilization has been demonstrated to be capable of resolving symptoms observed in individuals diagnosed with internal shoulder impingement.[50]

Measurement of strength characteristics provides insight into both injury prevention and performance optimization. Our previous research has demonstrated that athletes who perform at elite levels typically have developed greater strength than those athletes who perform at recreational levels and that strength is significantly correlated to performance.[23] Additionally, our research examining female athletes who are at greater risk for ACL injury demonstrate decreased quadriceps and hamstrings strength compared to male athletes.[51] Other individuals have demonstrated that inadequate agonist/antagonist strength ratios (quadriceps/hamstrings) can predict both ligamentous injury[52] and muscular injury such as hamstring strains.[53-55] In the current study, the 101st Soldiers (both males and females) had lower knee flexor, knee extensor, and flexion/extension strength ratios compared to the triathletes, all of which may indicate a propensity for injury. The analysis utilized in the current study was based on a comparison of means which may not be as important as a subject by subject examination of data. Within each variable data set there are individuals who had very low strength values compared to both the mean of the triathletes and also the mean of the 101st Soldiers. For instance, 17% of the male Soldiers and 19% of the female Soldiers had hamstring strength values that were lower than one standard deviation below the respective means of the male and female triathletes. These individuals will particularly benefit from an intervention program as they theoretically may have greater potential for improvement.

Overall, there were no significant differences in balance between Soldiers of the 101st and the triathletes. Balance testing has been previously utilized to examine risk of injury and or potential risk of injury.[56-62] Although the mean of the Soldiers tested is not significantly different than those triathletes tested, there remains a subgroup of Soldiers who may be at greater risk for injury. A systematic review of studies examining the relationship between ankle injuries and balance demonstrated that poor balance is associated with lateral ankle sprains.[63] Those individuals with the lowest balance scores were more likely to suffer an ankle injury than those with the best scores. Although methodological differences exist between the previous studies and the current manuscript, with prospective data it will be possible to set a criterion below which an individual would be at greater risk for injury. It is more than likely that with such a large group of individual tested in the current study, there are individuals who will suffer ankle injuries and likely their scores on the balance test would reveal this potential risk. For example, McGuine et al., examined, prospectively, 210 individuals balance and demonstrated that the 23 individuals who suffered an ankle sprain had balance scores that were 15% worse than the mean.[64] Willems et al., performed a similar study that demonstrated that the 44 individuals (out of 241) who suffered an ankle sprain had balance scores that were 24% worse than the mean.[65] Within the current study's Soldier group, 23% (61/266) of the males and 20% (10/51) of the females were worse than 15% of the mean and 19% (51/266) of the males and 14% (7/51) of the females who were worse than 25% of the mean (eyes open balance test).

The majority of physiological comparisons revealed that the triathletes had greater aerobic and anaerobic capacity as well as less body fat than the 101st Soldiers. Without appropriate context it is difficult to determine the clinical relevance of these results for the 101st Soldiers, but overall, the results do reveal a need to revise current training activities in order to optimize these physiological systems and characteristics to meet the demands placed on the individual Soldier. Our *Task and Demand Analysis* step provides the bridge between the physiological and physical demands of 101st Soldiers and the physical training necessary to meet those demands. For example, the data presented for the *Task and Demand Analysis* section in the current manuscript demonstrated the need for anaerobic training based on the Soldier's reliance on the anaerobic energy system as a significant contributor to the muscle fuel requirements during the O-Course training.

Although there were no significant differences in the biomechanical characteristics between the 101st Soldiers and the triathletes, a more careful examination of the data indicates that the Soldiers may display characteristics that could predispose them to injury. Prospective studies have demonstrated that landing with high vertical ground reaction forces and with a large knee valgus angle predict knee ligament injury.[58] Additionally, although not demonstrated prospectively, landing with a low flexion angle can increase anterior cruciate ligament strain significantly.[46, 67-70] Both male and female Soldiers had a subset of individuals who landed with a knee valgus angle greater than five degrees, which has been identified as a predictor of anterior cruciate ligament (ACL) injury.[66] Additionally, the mean values for peak vertical ground reaction force in the Soldiers (both genders) was approximately 365% body weight which is much higher than those values observed in a group of athletes who suffered ACL ruptures (210% body weight).[44] Finally, the knee flexion angle at landing in the male Soldiers was less than 20 degrees which can increase strain considerably in the ACL compared to greater knee flexion angles.[46, 67-70] The comparisons above are limited based on slightly different protocols between the current study and the referenced studies. They only indicate the potential for injury and not necessarily risk for injury. Regardless, it demonstrates that there are Soldiers who demonstrate potentially injurious biomechanical characteristics during tasks when knee injuries occur that indicate the need for training activities that target modification of motion patterns and strength. This potential for injury may be exacerbated while wearing body armor as our previous study has demonstrated that the addition of body armor significantly increases ground reaction forces and landing kinematics.[30]

In summary the laboratory data collected including the comparisons to the *Task and Demand Analysis* data and the comparisons to triathletes provides the part of the framework for the design of the intervention. Triathletes were used as a comparison for the current manuscript, but other groups of athletes (hockey, football, soccer, and basketball) have also been tested in order to benchmark the 101st Soldiers to individuals who have optimized different physical characteristics. For example, the group of triathletes in the current study have all competed in accredited full-length triathlons and have qualified (age group) for world championship events. Presumably, this group of athletes has optimized aerobic conditioning as well as anaerobic capacity. Depending on the target study group, Soldiers of the 101st in the current manuscript, this data can serve as a benchmark for specificity of training. Other groups of athletes can serve a similar purpose related to other characteristics. Although the laboratory tests utilized in the current study may not be functional tasks that Soldiers perform, we contend that the characteristics (strength, aerobic capacity, anaerobic capacity, balance, and flexibility) measured describe the underlying components/processes necessary for the performance of functional tasks of the Soldier. Therefore, improvements in these characteristics should provide the foundation for improvements in functional tasks of the Soldier. The injury data (currently being tracked and part of the ongoing investigation) combined with the prospective testing of

Soldiers will also dictate specific activities for the intervention. One potential limitation for the comparison group in the current study is the age of the triathletes. The mean age of the triathletes was approximately seven years older than the Soldiers mean age. This difference in age may confound the comparisons and subsequent results. Age was not controlled in the current manuscript due to the low subject numbers in the triathlete group. Other potential confounding were also not controlled (nutrition, tobacco use, sleep (quality and amount), and supplementation and may warrant further investigation

Conclusions

Unintentional musculoskeletal injuries are preventable with scientifically driven and culturally-specific interventions. Our approach is based on a conventional public health model of injury prevention. The model of research described in the current paper and Part II of these companion papers describes a specific application to the 101st Airborne Division (Air Assault). This model, by design, can be implemented in any population of military personnel, including Special Operations Forces. It may be particularly suited to application in Special Operations Forces due to the elite athlete benchmarking and the ability to individualize to the specific needs of each Operator. Through *Injury Surveillance*, we have demonstrated that Soldiers of the 101st continue to suffer common and preventable injuries during physical training, tactical training, sports, and recreational activities. Our *Task and Demand Analysis*, which is the hallmark of our comprehensive approach, drives the specificity of the testing methodology and contributes to the *Design and Validation of Interventions*. The task and demand analyses performed for this study demonstrated the need to test multiple flexibility, range of motion, strength, physiological, and biomechanical variables in order to determine risk factors for injury. The data analysis identified a number of characteristics of 101st Soldiers that should be targeted with specific physical training. Part II of these companion papers outlines the *Design and Validation of Interventions* for the 101st, the process of *Program Integration and Implementation*, and the methods to *Monitor and Determine the Effectiveness of the Program*.

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