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.

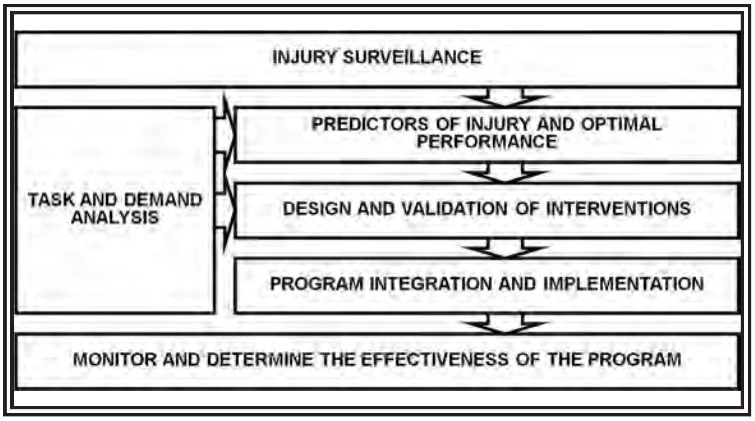

Figure 1: *University of Pittsburgh Injury Prevention and Performance Optimization Model*

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.

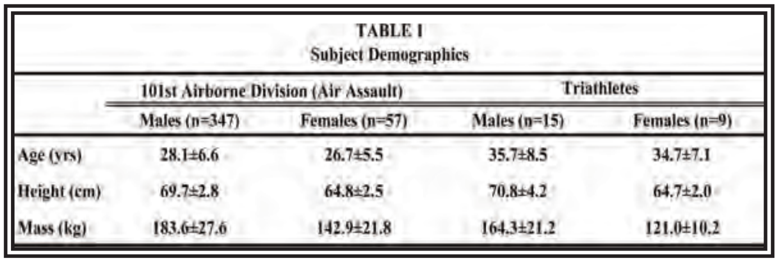

TABLE 1
Subject Demographics

	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

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.

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.

Data Reduction

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)

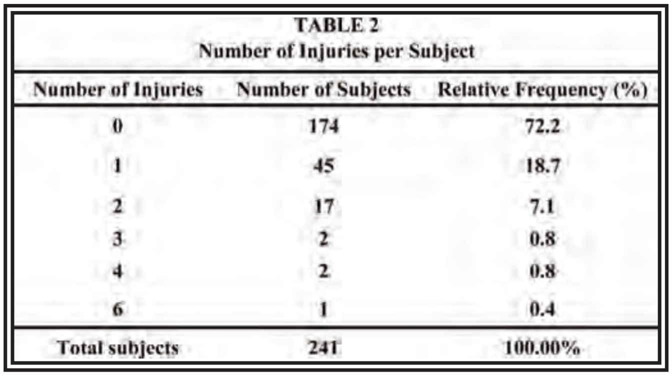
TABLE 2
Number of Injuries per Subject

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

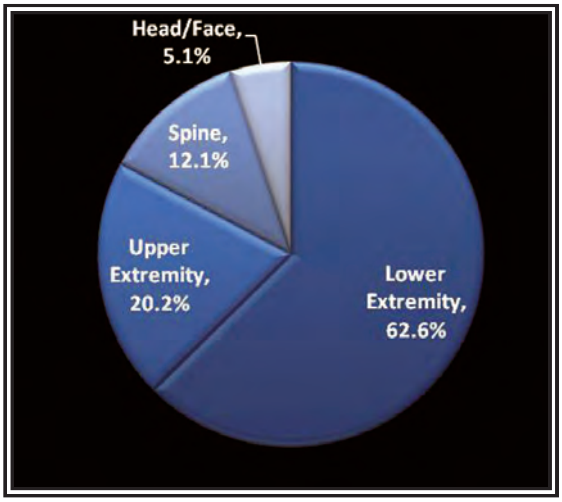

Figure 4: *Anatomic location of the injuries*

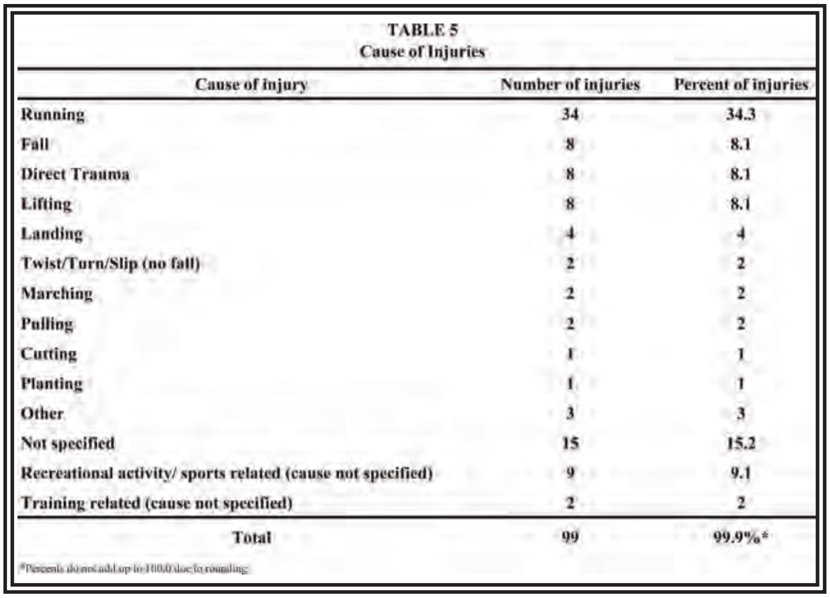

TABLE 5
Cause of Injuries

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 100.0 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).

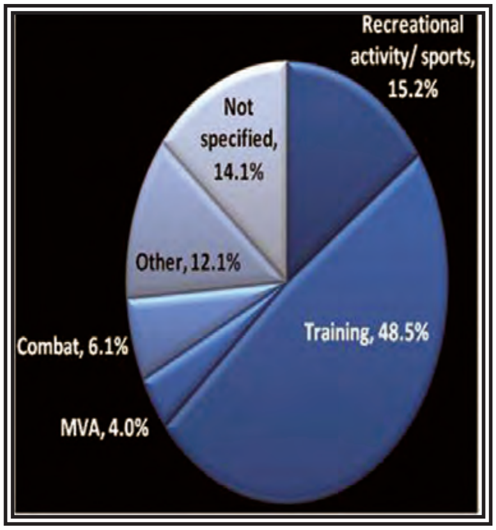

Figure 5: *Activity when injury occurred*

Task and Demand Analysis

<u>Task Analysis</u>

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.

<u>Demand Analysis</u>

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.

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.

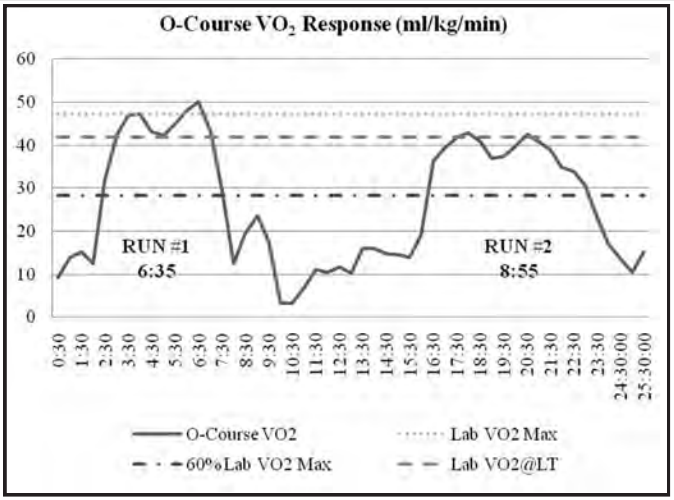

Figure 6: *VO2 response during the O-Course*

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.

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 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

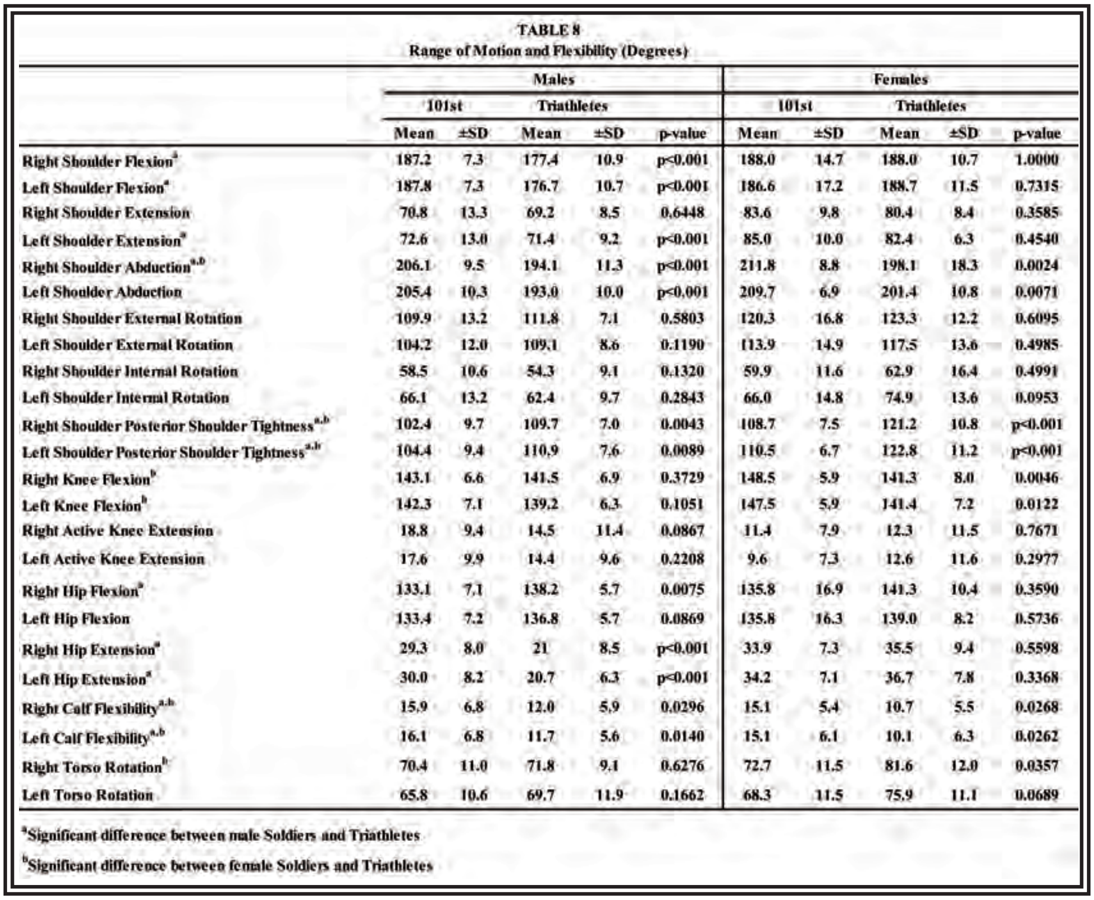

TABLE 8
Range of Motion and Flexibility (Degrees)

	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

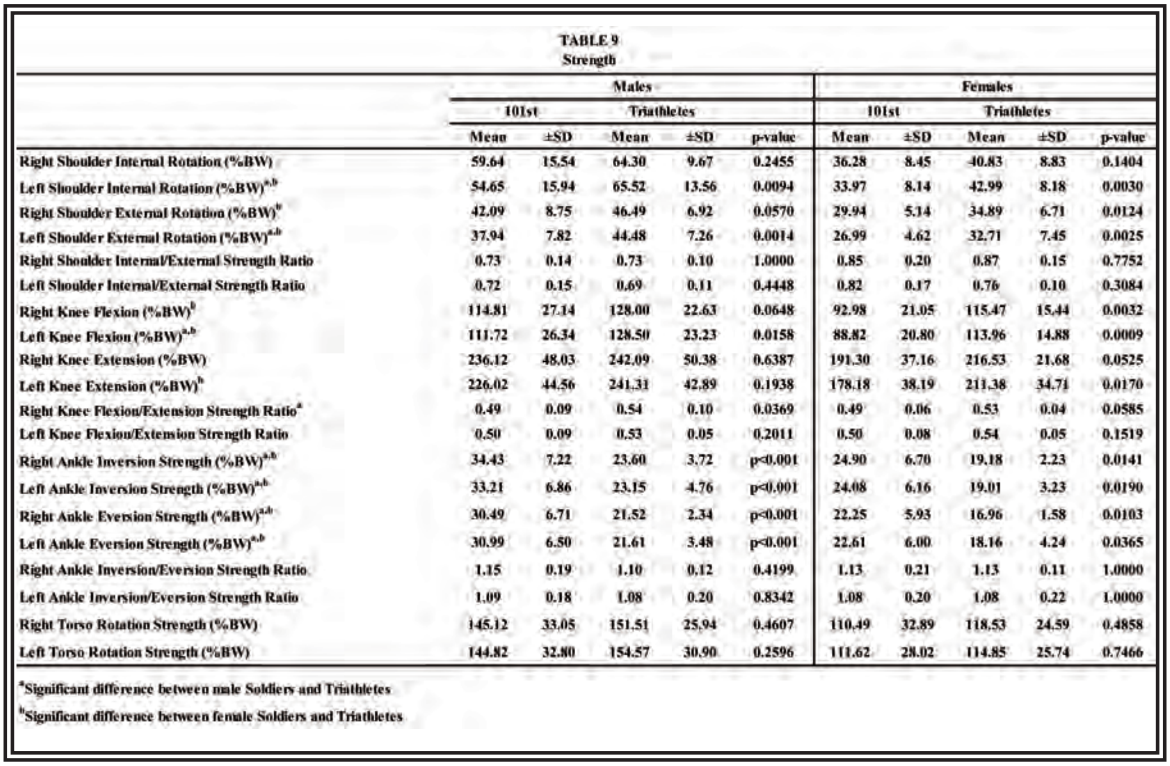

TABLE 9
Strength

	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-

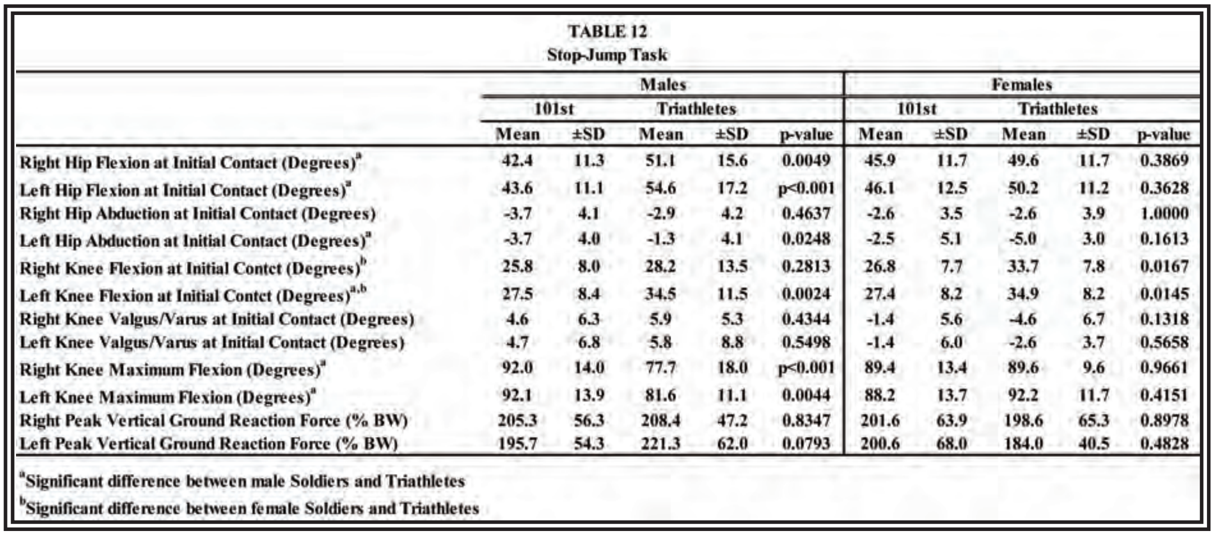

TABLE 12
Stop-Jump Task

	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-

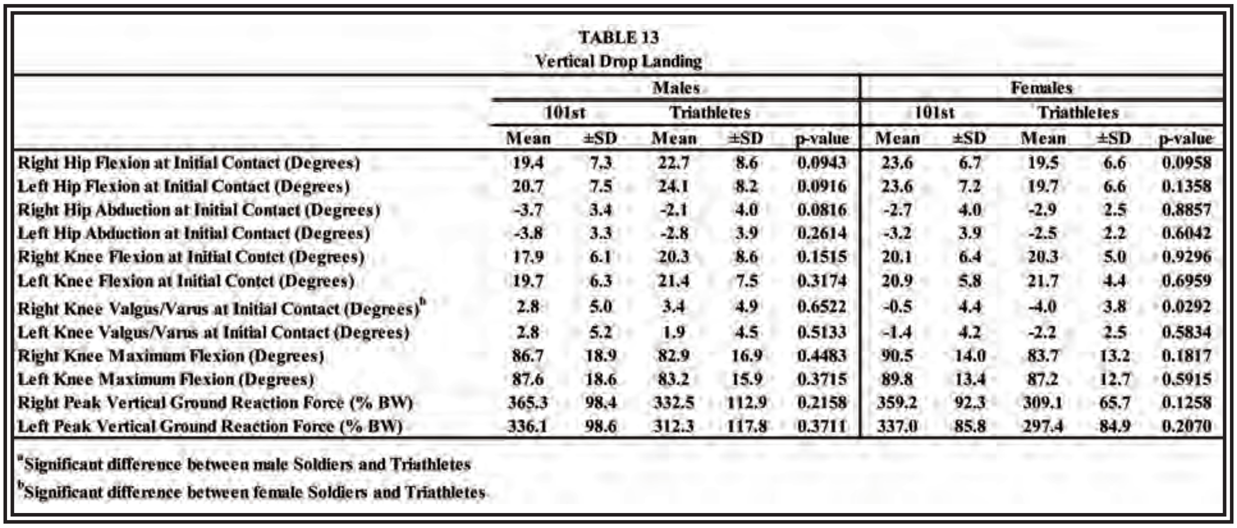

TABLE 13
Vertical Drop Landing

	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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