Musculoskeletal, Biomechanical, and Physiological Gender Differences in the US Military

Katelyn F. Allison, PhD
Karen A. Keenan, PhD, ATC
Timothy C. Sell, PhD, PT
John P. Abt, PhD, ATC
Takashi Nagai, PhD, ATC
Jennifer Deluzio, MS
COL Mark McGrail, MC, USA
Scott M. Lephart, PhD

Abstract

The repeal of the Direct Ground Combat Assignment Rule has renewed focus on examining performance capabilities of female military personnel and their ability to occupy previously restricted military occupational specialties. Previous research has revealed female Soldiers suffer a greater proportion of musculoskeletal injuries compared to males, including a significantly higher proportion of lower extremity, knee, and overuse injuries. Potential differences may also exist in musculoskeletal, biomechanical, and physiological characteristics between male and female Soldiers requiring implementation of gender-specific training in order to mitigate injury risk and enhance performance.

Purpose: To examine differences in musculoskeletal, biomechanical, and physiological characteristics in male and female Soldiers.

Methods: A total of 406 101st Airborne Division (Air Assault) Soldiers (348 male; 58 female) participated. Subjects underwent testing for flexibility, isokinetic and isometric strength (percent body weight), single-leg balance, lower body biomechanics during a stop jump and drop landing, body composition, anaerobic power/capacity, and aerobic capacity. Independent *t* tests assessed between-group comparisons.

Results: Women demonstrated significantly greater flexibility ($P<.01$-$P<.001$) and better balance ($P\leq.001$) than men. Men demonstrated significantly greater strength ($P\leq.001$), aerobic capacity (47.5±7.6 vs 40.3±5.4 ml/kg/min, $P<.001$), anaerobic power (13.3±2.1 vs 9.5±1.7 W/kg, $P<.001$), and anaerobic capacity (7.8±1.0 vs 6.1±0.8 W/kg, $P<.001$) and lower body fat (20.1±7.5 vs 26.7±5.7 (%BF), $P<.001$). Women demonstrated significantly greater hip flexion and knee valgus at initial contact during both the stop jump and drop landing tasks and greater knee flexion at initial contact during the drop landing task ($P<.05$-$P<.001$).

Conclusions: Gender differences exist in biomechanical, musculoskeletal, and physiological characteristics. Sex-specific interventions may aid in improving such characteristics to optimize physical readiness and decrease the injury risk during gender-neutral training, and decreasing between-sex variability in performance characteristics may result in enhanced overall unit readiness. Identification of sex-specific differences in injury patterns and characteristics should facilitate adjustments in training in order for both sexes to meet the gender-neutral occupational demands for physically demanding military occupational specialties.

Women have historically played an important role in the US military despite facing restrictions on unit assignment.[1] Since the repeal of the Direct Ground Combat and Assignment Rule, the US armed forces renewed focus on evaluation of women performing in previously-restricted military occupational specialties (MOSs) by assessing sex-neutral performance standards and training capabilities. Previous research demonstrated male and female athletes and military personnel possess different musculoskeletal, biomechanical, and physiological profiles[2-4] and suffer musculoskeletal injuries at differing rates and severity.[5] Physical, physiological, and musculoskeletal profiles of male and female military personnel are important to determine the potential for women to safely and successfully occupy newly-opened MOSs, and if modifiable risk factors for performance and injury can be addressed in sex-specific physical training programs.

Epidemiological research has explored injury rates, types, and causes in military personnel.[5-9] Studies investigating nonbattle injuries sustained during deployment revealed female Soldiers had a significantly higher incidence of injury than male Soldiers.[10,11] Other research indicated female Soldiers sustain a greater proportion of lower extremity and overuse injuries.[6-8] Researchers reporting 50% of female Soldiers will sustain one or more injury, including stress fractures, by the end of Basic Combat Training, postulated the increased rate of injury in female Soldiers may be because female and male Soldiers of differing fitness levels participate in the same training.[12] Although the reason(s) for sex differences in injury rates, types, and causes are unclear, they may result from sex differences in physical, physiological, and musculoskeletal characteristics and differences in training intensity during basic combat training, daily physical training, and deployment.

Previous research evaluating requirements for physically-demanding jobs, like lifting, carrying, pushing/pulling loads, and basic soldiering tasks, identified components of fitness necessary for safe and successful completion of these tasks, including strength, power, endurance, mobility, and flexibility.[13,14] It is well known that female Soldiers, on average, possess less absolute strength and force generating capacity, less endurance and higher fatigability during repetitive tasks, and less aerobic capacity than male Soldiers.[14] Studies investigating movement patterns of military personnel also demonstrated significant sex differences in parachute landing techniques that may contribute to ACL injury risk,[15,16] which is important in airborne units. Sex disparities in physical, physiological, and musculoskeletal characteristics should be examined further in contemporary military populations to determine the capability of women to safely and successfully perform strenuous occupational tasks and to reduce performance gaps between sexes.

The purpose of this study was to investigate potential sex differences across a comprehensive set of physical, physiological, musculoskeletal, and biomechanical characteristics within a modern military population. It was hypothesized that male and female Soldiers would display significantly different physical, physiological, musculoskeletal, and biomechanical profiles. If differences in characteristics are identified, targeted, gender-specific physical training may increase overall force readiness and resiliency, especially as women are integrated into previously restricted MOSs.

Materials and Methods

Subjects

A total of 406 Soldiers (348 male, 58 female) of the 101st Airborne Division (Air Assault) at Fort Campbell, Kentucky, participated in this study. Demographic information is presented in Table 1. Subjects are a subset of subjects enrolled in the Human Performance and Injury Prevention Initiative (Eagle Tactical Athlete Program) 6-step model derived from the public health model of injury prevention and control.[9,17] All subjects met the following criteria: 18 to 45 years of age and no current medical or musculoskeletal conditions that prevented full active duty. Human protection for the current study was approved by the appropriate civilian and military institutional review boards. Written informed consent was obtained from each subject prior to participation in this study.

Procedures

Testing occurred over 2 days (approximately one week apart) at the University of Pittsburgh Human Performance Research Center (Fort Campbell). Each session lasted 2 hours. Testing was performed bilaterally where applicable; only right-sided data is presented, as no between side differences were noted.

A standard goniometer or digital inclinometer was used to measure passive range of motion of the shoulder, hip, and knee (flexion) and active range of motion of the knee (extension) and ankle.[18] Reliability of these measurements has been previously established.[19,20] 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. The Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY) measured active torso range of motion, with the subject seated and actively rotating in the right and left directions.

The Biodex Multi-Joint System 3 Pro measured shoulder internal/external rotation, shoulder abduction/adduction, hip abduction/adduction, knee flexion/extension, ankle plantarflexion/dorsiflexion, and torso rotation strength. The reliability of isokinetic strength testing has been previously established for peak torque/body weight (intraclass correlation coefficient [ICC]=0.73-0.97).[21] For shoulder, knee, and torso strength testing, subjects

Table 1. Subject Demographics

	Men			Women			*P* Value
	n	Mean	±SD	n	Mean	±SD	
Age (years)	348	28.06	6.63	58	26.72	5.48	.147
Height (m)[a]	348	1.77	0.07	58	1.65	0.06	<.001
Weight (kg)[a]	348	83.48	12.57	58	64.93	9.90	<.001

[a]Statistically significant difference between men and women (*P*<.05).

performed 3 practice trials at 50% maximum effort followed by 3 more at 100% effort. Following a rest period of 60 seconds, 5 repetitions of reciprocal concentric isokinetic testing were performed at 60° per second. Hip abduction/adduction was assessed isometrically in a sidelying, neutral hip position. Subjects performed 3 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 3 sets of 5-second isometric contractions, alternating between plantarflexion and dorsiflexion.

A hand held dynamometer (Lafayette Instrument Company, Lafayette, IN) assessed ankle inversion and eversion strength. Strength measured via hand held dynamometry has been demonstrated to be reliable for ankle inversion and eversion (ICC=0.84-0.86 and ICC=0.74-0.85, respectively)[22,23] and is a valid measurement of ankle strength.[22-24] Ankle inversion and eversion strength was tested with the subject long-sitting with the foot and ankle off the end of the table.

A single force plate (Kistler 9286A, Amherst, NY), with a sampling frequency of 100 Hz, measured balance. Three, 10 second trials of single-leg standing balance were performed with subjects barefooted with their hands on their hips, with eyes opened and eyes closed conditions based on Goldie et al.[25,26] This protocol was previously demonstrated valid and reliable.[20,25-27] Trials were discarded and recollected if the subject's nonstance leg hit the stance limb or the ground outside of the force plate. Subjects were permitted to briefly touch down on the force plate with their non-stance leg and immediately lift the leg back into test position.

A portable metabolic system (OxyCon Mobile, Viasys, Yorba Linda, CA) and lactate analyzer (Arkray, Inc, Kyoto, Japan) captured maximal oxygen consumption (VO_2max) and lactate threshold during an incremental ramp protocol. The OxyCon Mobile has been demonstrated as a valid metabolic system with less than 3% difference compared to simulated VO_2 during a maximal cardiopulmonary exercise test.[28] Following a 5-minute warm-up, the test was performed in 3-minute stages, with the initial 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 2-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 prior to an increase in incline in order to assess blood lactate levels. Heart rate (Polar USA, Lake Success, NY) and VO_2 were collected and monitored continuously throughout the test. Relative VO_2max, maximum heart rate, VO_2 at lactate threshold, percent of VO_2max at lactate threshold, heart rate at lactate threshold, and percentage of maximum heart rate at lactate threshold were reported.

An electromagnetic cycle ergometer (RacerMate, Inc, Seattle, WA) measured anaerobic power and capacity during a Wingate protocol,[29] which has been previously demonstrated as a highly valid and reliable test of these variables.[30] Following a warm-up at a self-selected cadence at 125 watts, the 50-second protocol was performed: 15 seconds maintaining 100 RPM at 125 W with minimal resistance; 5 seconds sprinting to generate maximum speed prior to initiation of normalized resistance; and 30 seconds attempting to sprint and maintain maximal speed against the normalized resistance. Braking torque was standardized to 9% and 7.5% body weight for men and women, respectively.

The Bod Pod Body Composition System (Life Measurement Instruments, Concord, CA) assessed body composition, which has previously demonstrated reliability (ICC=0.98, SEM=0.47% BF)[21] and validity.[31] Men wore spandex shorts and a swim cap while women wore spandex shorts, a sports bra, and swim cap. Once 2 consistent body volume measurements were obtained, percent body fat was calculated using predicted lung volume and the appropriate body densitometry equation; body mass index (BMI) was also calculated.

Six high-speed cameras (Vicon, Centennial, CO) with 200 Hz sampling frequency captured biomechanical data during an athletic task (stop jump task) and functional landing task (drop landing task). Following Vicon's Plug-in-Gait model, 16 retro-reflective markers were affixed to the anterior superior iliac spine, posterior superior iliac spines lateral thigh, lateral femoral condyle, lateral lower leg, lateral malleous, posterior calcaneus, and head of the second metatarsal. Appropriate anthropometrics were measured with an anthropometer (Lafayette Instrument, Lafayette, IN). A static trial in an anatomical neutral position captured a baseline for joint angle calculations. The accuracy and validity of the Plug-in Gait model have been previously established.[32-34] The stop jump task was a standing broad jump, initiated from a normalized distance of 40% of the subject's height, followed immediately (after landing on the force plates) by a maximal effort vertical jump. The drop landing was initiated by subjects leaning forward while standing on a standardized, 0.51 meter high platform, allowing gravity to drive the drop movement, followed by landing with one foot on each of the force plates (1200 Hz).

Data Processing and Reduction

Flexibility/range of motion and handheld dynamometer strength measures were averaged across 3 trials. Strength obtained with The Biodex dynamometer was reported as the peak average torque across 5 trials normalized to each subject's individual body mass.

For VO_2max data, a 15-second moving window was used to filter metabolic data in order to reduce the overall breath-by-breath data points. Maximal oxygen uptake was calculated as the highest consecutive oxygen uptake levels over one minute of data collection relative to body mass. Lactate threshold was identified by the inflection point when blood lactate levels increased by one mmol/L or more between stages. Anaerobic power output was identified as the peak power within the first 5 seconds of the test following resistance initiation, while anaerobic capacity was calculated as the mean power output over the 30 seconds of the test following resistance initiation normalized to body mass.

For both balance and biomechanical data, force plate data were passed through an amplifier and analog to a digital board (DT3010, Digital Translation, Marlboro, MA) and stored on a personal computer. A custom MATLAB Version 7.0.4 (MathWorks, Inc, Natick, MA) script processed ground reaction force data. For eyes opened and eyes closed balance conditions, the standard deviation for the ground reaction forces for each direction (anterior-posterior, medial-lateral, vertical) was calculated and then averaged across all 3 trials. Prior to calculation of joint kinematics, the Vicon Nexus software reconstructed 3-dimensional trajectories of the reflective markers, and smoothed with a general cross-validation Woltring filter. Trajectories of hip, knee, and ankle joint centers were estimated based on marker locations and anthropometric parameters according to Vicon's Plug-in Gait model. Joint kinematics including the following variables were calculated for the stop jump and drop landing tasks: hip flexion and abduction angles at initial contact, knee flexion and valgus/varus angles at initial contact, and maximum knee flexion angle. The maximum vertical ground reaction force was identified for each trial. Data were averaged across the 3 trials prior to analysis.

Statistical Analysis

All variables were assessed for normality and frequency distribution. The mean and standard deviation were calculated for each of the variables included in the study. All variables were analyzed with independent *t* tests to examine potential sex differences. An alpha level of 0.05 was chosen a priori to denote statistical significance for comparisons. Statistical analyses were performed with IBM SPSS Statistics Version 19.0 (IBM Corp, Armonk, NY).

Results

Range of motion and flexibility data are presented in Table 2. Female Soldiers demonstrated significantly greater shoulder extension, abduction, and external rotation range of motion and hip extension and knee flexion. Female Soldiers had significantly lower values for active knee extension, indicating significantly better hamstring flexibility than male Soldiers. Female Soldiers also had significantly more range of motion for the posterior shoulder tightness test, indicating less posterior shoulder tightness than male Soldiers.

Table 2. Range of Motion and Flexibility (in degrees)

	Men			Women			*P* Value
	n	Mean	±SD	n	Mean	±SD	
Shoulder Flexion	160	187.2	7.3	35	188.0	14.7	.636
Shoulder Extension[a]	338	70.8	13.3	56	83.6	9.8	<.001
Shoulder Abduction[a]	159	206.1	9.5	34	211.8	8.8	.002
Shoulder External Rotation[a]	340	109.9	13.2	57	120.3	16.8	<.001
Shoulder Internal Rotation	340	58.5	10.6	57	59.9	11.6	.399
Posterior Shoulder Tightness[a]	299	102.4	9.7	52	108.7	7.5	<.001
Knee Flexion[a]	156	143.1	6.6	33	148.5	5.9	<.001
Active Knee Extension[a]	340	18.8	9.4	57	11.4	7.9	<.001
Hip Flexion	170	133.1	7.1	35	135.8	16.9	.126
Hip Extension[a]	340	29.3	8.0	56	33.9	7.3	<.001
Calf Flexibility	340	15.9	6.8	57	15.1	5.4	.399
Torso Rotation	341	70.4	11.0	57	72.7	11.5	.147

[a]Statistically significant difference between men and women ($P<.05$).

Strength data are presented in Table 3. Female Soldiers demonstrated significantly weaker shoulder internal and external rotation and shoulder abduction and adduction. Shoulder internal/external rotation strength ratio was significantly higher in female Soldiers. Knee flexion and extension, ankle inversion, eversion, and dorsiflexion and torso rotation were significantly lower in female Soldiers.

Balance data are presented in Table 4. Male Soldiers demonstrated significantly higher anterior/posterior, medial/lateral, and vertical scores bilaterally, under both eyes open and eyes closed conditions. Higher scores represent poor balance.

Physiology data are presented in Table 5. Female Soldiers demonstrated significantly higher BMI and body fat percentage. Male Soldiers had significantly higher anaerobic power, anaerobic capacity, VO_2max, and VO_2 at lactate threshold.

Biomechanical data are presented in Table 6 for the stop-jump task and vertical drop landing. Female Soldiers demonstrated significantly greater hip flexion at initial contact and greater knee valgus at initial contact during both the stop jump and drop landing tasks. Female Soldiers demonstrated significantly greater knee flexion at initial contact during the drop landing task.

Table 3. Strength

	Men			Women			P Value
	n	Mean	±SD	n	Mean	±SD	
Shoulder Strength							
Internal Rotation (%BW)[a]	334	59.6	15.5	57	36.3	8.5	<.001
External Rotation (%BW)[a]	334	42.1	8.8	57	29.9	5.1	<.001
Internal/External Strength Ratio[a]	334	0.73	0.14	57	0.85	0.20	<.001
Abduction (%BW)[a]	169	78.1	15.2	24	55.3	6.7	<.001
Adduction (%BW)[a]	169	83.1	25.5	24	55.7	16.2	<.001
Abduction/Addubction Strength Ratio	169	1.00	0.30	24	1.16	0.87	.077
Knee Strength							
Flexion (%BW)[a]	334	114.8	27.1	57	93.0	21.1	<.001
Extension (%BW)[a]	334	236.1	48.0	57	191.3	37.2	<.001
Flexion/Extension Strength Ratio	334	0.49	0.09	57	0.49	0.06	1.000
Hip Strength							
Abduction (%BW)	169	167.3	34.2	24	158.8	32.9	.254
Adduction (%BW)	169	148.1	35.8	24	139.5	30.4	.264
Abduction/Adduction Strength Ratio	169	0.89	0.18	24	0.89	0.19	1.000
Ankle Strength							
Plantar Flexion (%BW)	150	133.6	45.9	22	120.9	44.9	.226
Dorsiflexion (%BW)[a]	150	45.4	10.2	22	37.40	8.1	.001
Plantar Flexion/Dorsiflexion Strength Ratio	150	3.06	1.20	22	3.44	1.59	.186
Inversion Strength (kg)[a]	335	34.4	7.2	57	24.9	6.7	<.001
Eversion Strength (kg)[a]	335	30.5	6.7	57	22.2	5.9	<.001
Inversion/Eversion Strength Ratio	335	1.15	0.19	57	1.13	0.21	.470
Torso Strength							
Rotation (%BW)[a]	340	145.1	33.1	57	110.5	32.9	<.001

[a]Statistically significant difference between men and women (*P*<.05).
BW indicates body weight.

Comment

The elimination of the Direct Ground Combat and Assignment Rule and the potential for an increased number of female service members in combat arms warrants examination of potential sex differences that may result in decreased performance and increased injury risk depending on occupational task requirements. The purpose of this study was to assess musculoskeletal, biomechanical, and physiological differences between sexes in a modern military population. Significant between-sex differences were found in Soldiers of the 101st Airborne Division (Air Assault) in range of motion and flexibility, strength, static balance, physiology, and biomechanics. However, within-sex variability of characteristics and specific occupational task requirements should be considered when determining individual job-specific performance capabilities and injury risk.

Table 4. Single-leg Balance: Variability (SD) in Ground Reaction Forces (N)

	Men			Women			P Value
	n	Mean	±SD	n	Mean	±SD	
Eyes Open							
Anterior/Posterior[a]	267	2.78	0.86	51	2.02	0.55	<.001
Medial/Lateral[a]	266	3.44	1.16	51	2.43	0.96	<.001
Vertical[a]	267	4.65	2.19	51	3.18	1.34	<.001
Eyes Closed							
Anterior/Posterior[a]	267	6.44	2.66	51	4.43	1.77	<.001
Medial/Lateral[a]	266	10.11	4.57	51	6.15	2.39	<.001
Vertical[a]	267	14.53	12.22	51	8.61	5.52	.001

[a]Statistically significant difference between men and women (*P*<.05).

Male Soldiers demonstrated significantly less range of motion and flexibility in both lower and upper extremities compared to female Soldiers. Previous research demonstrated deficits in range of motion or flexibility increase risk of acute and overuse musculoskeletal injuries,[35-39] while high or excessive flexibility has also been demonstrated to increase the risk of musculoskeletal injury.[7] A previous study identified Australian footballers with greater than 27° of knee flexion during active knee extension were almost 3 times more likely to sustain a hamstring strain (RR=2.8; 95% CI, 0.9-8.5). However, both men and women in the current study were, on average, well below this threshold.[40] Men with first and third tertiles for hamstring flexibility assessed with the sit-and-reach test were at more than 2 times the risk to sustain a time-loss injury during basic combat training than those in the middle tertile.[7] No such relationship was seen in women in basic combat training. Other researchers demonstrated decreased knee flexion and quadriceps flexibility increase the risk of quadriceps muscle injury, patellofemoral pain syndrome, and patellar tendinitis.[37-39] Similarly, subjects with shoulder instability and impingement demonstrated deficits in shoulder range of motion.[41] However, due to methodological differences in testing positions and the use of

Table 5. Physiology

	Men			Women			P Value
	n	Mean	±SD	n	Mean	±SD	
Body Mass Index (kg/m^2)[a]	347	23.0	2.9	58	24.0	3.1	.017
Body Fat (%)[a]	338	20.1	7.5	57	26.7	5.7	<.001
Anaerobic Power (watts/kg)[a]	326	13.3	2.1	56	9.5	1.7	<.001
Anaerobic Capacity (watts/kg)[a]	326	7.8	1.0	55	6.1	0.8	<.001
VO_2 Max (mL/kg/min)[a]	322	47.5	7.6	54	40.3	5.4	<.001
VO_2 at Lactate Threshold (mL/kg/min)[a]	320	39.0	7.0	54	33.5	5.5	<.001
VO_2% at Lactate Threshold	320	81.8	10.3	54	82.2	14.0	.803
HR Max (bpm)	322	188.6	14.2	53	188.9	9.6	.882
HR at Lactate Threshold (bpm)	319	169.4	15.3	53	171.4	12.1	.366
HR% at Lactate Threshold	319	89.6	7.2	53	91.0	5.2	.176

[a]Statistically significant difference between men and women (*P*<.05).

pathological populations in these studies, comparisons cannot be made between the results from these studies and those in the current study. Further, no threshold for increased injury risk was reported in any of these studies. Based on this previous research and current findings, it may be beneficial for Soldiers, regardless of sex, with less flexibility/range of motion to incorporate flexibility exercises into training to decrease injury risk. Future research should investigate if such thresholds exist (and if they are gender-specific) using the methods in the current study, which are representative of typical goniometric measures obtained in clinical settings.

Female Soldiers demonstrated strength deficits compared to men even after normalization to body mass. Yet, in the US Army, male and female Soldiers may be called upon to perform the same occupational tasks. Strength differences may put female Soldiers at increased risk of unintentional musculoskeletal injury while performing the duties required of their positions. Additionally, since women generally use a greater percentage of their absolute strength than males during high intensity repetitive tasks, they are more likely to fatigue earlier,[14] and may be at higher injury risk due to compensated technique. Previous research revealed targeted resistance training programs result in increased performance on military specific tasks and reduce gender disparity in strength and occupational lifting/carrying tasks,[42,43] indicating these programs and subsequent adaptations are beneficial in increasing the proportion of women able to successfully perform physically demanding jobs.

Lower extremity strength deficits may contribute to increased injury risk. Weak hamstrings have been demonstrated to increase the risk of hamstring strain.[44] Lower hamstring to quadriceps ratios, falling below the optimal range of 0.60 to 0.90, increases the risk of hamstring strain and injury to the lower leg.[44,45] Although there was no significant difference between men and women in hamstring to quadriceps ratio, both demonstrated ratios (0.49 to 0.50) well below the ratios recommended for decreased injury risk. This may indicate training for both men and women should be adjusted to increase hamstring strength while maintaining quadriceps strength in order to achieve more favorable ratios. Female Soldiers possess less ankle dorsiflexion, inversion, and eversion strength than male Soldiers. Individuals with less ankle strength may be at increased risk for ankle sprains, chronic ankle instability, and other lower leg injuries,[46-49] so targeted programs may be beneficial for any Soldier with less ankle strength in order to reduce injury risk.

Female Soldiers demonstrated significantly weaker shoulder and torso musculature than male Soldiers. Tasks identified in Soldiers with physically-demanding MOSs (lifting/lowering, carrying/load bearing, pulling) each rely heavily on upper body and core strength. Individuals with shoulder instability and shoulder impingement have demonstrated deficits in shoulder strength.[41] Studies

Table 6. Biomechanical Analysis

	Men			Women			P Value
	n	Mean	±SD	n	Mean	±SD	
Stop-Jump Task							
Hip Flexion at Initial Contact (°)[a]	259	42.37	11.26	49	45.87	11.74	.048
Hip Abduction at Initial Contact (°)	259	-3.70	4.07	49	-2.58	3.48	.072
Knee Flexion at Initial Contact (°)	259	25.79	8.02	49	26.82	7.73	.408
Knee Varus/Valgus at Initial Contact (°)[a,b]	259	4.58	6.25	49	-1.36	5.58	<.001
Maximum Knee Flexion (°)	259	91.98	13.97	49	89.41	13.40	.236
Maximal Vertical GRF (%BW)	258	205.28	56.32	49	201.64	63.88	.685
Vertical Drop Landing							
Hip Flexion at Initial Contact (°)[a]	237	19.4	7.3	50	23.6	6.7	<.001
Hip Abduction at Initial Contact (°)	237	-3.7	3.4	50	-2.7	4.0	.068
Knee Flexion at Initial Contact (°)[a]	237	17.9	6.1	50	20.1	6.4	.022
Knee Varus/Valgus at Initial Contact (°)[a,b]	237	2.8	5.0	50	-0.5	4.4	<.001
Maximum Knee Flexion (°)	237	86.7	18.9	50	90.5	14.0	.264
Maximal Vertical GRF (%BW)	236	365.3	98.4	50	359.2	92.3	.688

[a]Statistically significant difference between men and women (*P*<.05).
[b]Negative value indicates valgus.

in civilians and in the workplace have associated low torso rotation strength with low back pain.[50,51] Soldiers with lower levels of strength may benefit from increasing upper body and torso strength in an attempt to decrease injury risk and increase performance capabilities.

Previous research demonstrated female Soldiers possess less absolute strength than males. However, data revealed some women are stronger than some men, and strength overlap is increased when strength is normalized for body mass and fat-free body mass.[14] This evidence suggests the ability to produce a muscle force is similar between sexes, but differences in quantity of muscle mass between males and females limits the absolute amount of force able to be generated.[14] In the current study, while female Soldiers, on average, possess less strength than male Soldiers, examination of individual variability among strength characteristics revealed the top performing women possess similar or better strength characteristics than the bottom performing men, indicating a potential strength capability overlap. Specifically, when assessed by percentiles, the top 25th percentile of women demonstrated greater shoulder strength than the bottom 10th percentile of men and better knee and torso strength than the bottom 25th percentile of men. The top 25th percentile of women demonstrated greater ankle plantar- and dorsiflexion than the bottom 50% of men, and the top 10th percentile of women demonstrated greater ankle inversion and eversion strength than the bottom 50% of men. Therefore, individual variability should be considered when assessing capabilities of male and female Soldiers to safely and successfully perform tactical activities. Strength overlaps should be interpreted with caution, as strength in the current study is normalized to body weight, and absolute strength sex overlaps are likely more conservative.

Male Soldiers demonstrated worse static balance than female Soldiers. Balance plays an important role in athletic and tactical tasks by providing a stable base of support and enhancing overall joint stability, especially with unstable surfaces or unexpected perturbations. Prospective studies demonstrated athletes with increased postural sway in the anterior/posterior and medial/lateral directions have increased risk of sustaining an ankle injury.[52-54] Female Soldiers may possess better balance, because, on average, the center of gravity/center of mass is lower than in male Soldiers. However, previous research revealed men tend to have better balance as the difficulty of the balance task increases, like during tasks involving dynamic postural stability.[55] Further research is warranted to investigate sex differences in postural control during more challenging tactical tasks and maneuvers.

Male Soldiers demonstrated significantly higher anaerobic power and capacity. These characteristics are reflective of the ability to perform quick burst activity and to sustain that performance for a period of time. By participating in training targeting anaerobic components of fitness, female Soldiers will be able to sprint faster and maintain a higher intensity longer. A limitation of the current study is the braking torque applied during the Wingate test differed for male and female Soldiers, so results must be interpreted with caution, and may differ compared to what would have been demonstrated with uniform braking torque.

Male Soldiers also had higher VO_{2max} and VO_2 at lactate threshold in the current study. Previous research postulated women may have reduced aerobic capacity because they carry less fat-free mass and a greater percentage of nonmetabolic (fat) tissue, have a lower oxygen carrying capacity, and possess a decreased cardiac output compared to males.[14,56] While VO_{2max} is largely based these factors, in addition to genetics and age, it can be positively affected by training. Perhaps more importantly, the point at which lactate threshold occurs is more readily influenced by training. If lactate threshold occurs at a higher percentage of maximal oxygen consumption, then an individual will be able to train at a higher intensity for a longer period of time. Individuals who train to enhance lactate threshold may be able to perform physical activity longer and at a higher intensity, thereby potentially improving performance and maximizing operational readiness. Overall, increasing cardiovascular fitness and anaerobic threshold may play a role in mitigating onset of fatigue and reducing risk of unintentional, musculoskeletal injuries.

When anaerobic and aerobic data was assessed by percentiles to investigate variance within sex, an overlap of capabilities was revealed. While considering the limitation of different braking torques, the top 25th percentile of women demonstrated better anaerobic power and capacity than the bottom 10th percentile of men. The top 25th percentile of women demonstrated better aerobic capacity than the bottom 25th percentile of men. The top 50% of women demonstrated a higher lactate threshold (%VO_{2max}) than the bottom 25th percentile of men. Therefore, physiological capabilities must be assessed on an individual level when determining job-specific injury risk and performance capabilities.

Female Soldiers demonstrated significantly higher BMI and body fat percentage than male Soldiers, similar to previous findings that female Soldiers possess 20% less overall body mass, 10% greater body fat, and 30% less muscle mass than their male counterparts.[57] Since fat-free mass is positively correlated with maximum muscular strength, and body fat is negatively correlated with aerobic capacity,[57,58] body composition plays an important role in force generating capacity and performance capability. Previous retrospective research found higher BMI is associated with increased injury risk, including plantar fasciitis and ankle sprain.[59,60] Higher body mass and BMI are prospectively demonstrated risk factors of injury to the low back and lower extremity in a military population.[61] Soldiers with lower (BMI<18 kg/m^2) and higher BMI (BMI>33 kg/m^2) had higher rates of medical and all-cause discharges compared to those classified into the median category (BMI=24.0-24.9 kg/m^2) during the first year of enlistment, suggesting Soldiers with a normal/average body composition are least likely to sustain an injury.[62] Soldiers with body fat percentages considered to be too high or too low may benefit from nutritional and physical training programs designed to optimize body composition to reduce injury risk, enhance performance, and augment health/longevity, but an appropriate range of body fat for male and female Soldiers should be assessed separately.

Biomechanical differences were found between male and female Soldiers during both the stop-jump and the vertical drop landing. Women tended to land with greater hip flexion and knee valgus at initial contact during both tasks. During the drop landing, women landed with increased knee flexion at initial contact, similar to previous research in the athletic population revealing sex differences in cutting, stopping, and jumping maneuvers.[2,27,63-65] Prospective research found individuals who land with greater knee valgus are at increased risk of anterior cruciate ligament injury.[66] Subjects with injury to the anterior cruciate ligament land with increased hip flexion compared to controls; similar increases have been noted in fatigued subjects.[67-69] Insufficient muscular strength and endurance may play a role in the increased hip flexion and knee valgus demonstrated by female Soldiers. Poor landing mechanics may be a function of these deficits coupled with a lack of training in proper landing mechanics. Previous research demonstrated training programs that address both strength and landing mechanics are able to improve landing biomechanics and reduce the injury risk.[70]

A limitation of the current study is the uneven distribution of male and female Soldiers available for analysis. However, the percentage of female Soldiers in the current study (≈14.3%) mirrors the approximate distribution of female Soldiers in the US Army (≈13.6%).[13] Another limitation is that job-specific tasks were not assessed in the current study. Future research should assess the performance of specific occupational tasks, especially those unique to ground combat units.

Conclusion

The current study demonstrated female Soldiers are significantly different from male Soldiers across a majority of physical, physiological, and musculoskeletal characteristics. Targeted training may be beneficial in order to address the sex-specific differences and to induce adaptions specific to job task requirements. While both male and female Soldiers possess the capability to perform physically-demanding job requirements, on average, female Soldiers possessed lower strength, power, endurance, and worse body composition and biomechanics than male Soldiers. Therefore, progressive, periodized programs designed to enhance these characteristics in female Soldiers may increase the proportion of women capable of safely and successfully performing job tasks and reduce the sex disparity evidenced in the current study. At the same time, within-sex variability of characteristics demonstrating the highest performing women possess comparable or better strength, anaerobic, and aerobic characteristics than the lowest performing men suggests military personnel should be evaluated on an individual (gender neutral) basis to determine performance capabilities, injury risk, and targeted program implementation. Overall, targeted, sex-specific training adaptations may be critical to improving overall force-wide safety, efficiency, and tactical preparedness, especially as female Soldiers are integrated into ground combat positions.

Acknowledgement

This work was supported by the US Army Medical Research and Materiel Command under Award No. W81XWH-06-2-0070/W81XWH-09-2-0095, W81XWH-11-2-0097.

References

1. Sharp MA. Physical fitness and occupational performance of women in the US Army. *Work*. 1994;4(2):80-92.
2. Lephart SM, Ferris CM, Riemann BL, Myers JB, Fu FH. Gender differences in strength and lower extremity kinematics during landing. *Clin Orthop Relat Res*. 2002(401):162-169.
3. Ford KR, Myer GD, Hewett TE. Valgus knee motion during landing in high school female and male basketball players. *Med Sci Sports Exerc*. 2003;35(10):1745-1750.
4. Lephart SM, Smoliga JM, Myers JB, Sell TC, Tsai YS. An eight-week golf-specific exercise program improves physical characteristics, swing mechanics, and golf performance in recreational golfers. *J Strength Cond Res*. 2007;21(3):860-869.

5. Tiesman H, Peek-Asa C, Zwerling C, Sprince N, Amoroso P. Occupational and non-occupational injuries in the United States Army: focus on gender. *Am J Prev Med*. 2007;33(6):464-470.

6. Knapik JJ, Jones SB, Darakjy S, et al. Injury rates and injury risk factors among US Army wheel vehicle mechanics. *Mil Med*. 2007;172(9):988-996.

7. Knapik JJ, Sharp MA, Canham-Chervak M, Hauret K, Patton JF, Jones BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc*. 2001;33(6):946-954.

8. Lovalekar M, Sell TC, Nagai T, House A, Pederson J, Lephart SM. Comparison of self-reported musculoskeletal injury history between female and male US Army Soldiers. Paper presented at: American Public Health Association 139th Annual Meeting and Exposition; October 29-November 2, 2011; Washington, DC.

9. Sell T, Abt J, Crawford K, et al. Warrior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part I. *J Spec Oper Med*. 2010;10(4):2-21.

10. Roy TC, Knapik JJ, Ritland BM, Murphy N, Sharp MA. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med*. 2012;83(11):1060-1066.

11. Skeehan CD, Tribble DR, Sanders JW, Putnam SD, Armstrong AW, Riddle MS. Nonbattle injury among deployed troops: an epidemiologic study. *Mil Med*. 2009;174(12):1256-1262.

12. Friedl K, Evans R, Moran D. Stress fracture and military medical readiness: bridging basic and applied research. *Med Sci Sports Exerc*. 2008;40(suppl 11):S609-S622.

13. Sauers SE, Scofield DE. Strength and conditioning strategies for females in the military. *Strength Cond J*. 2014;36(3):1-7.

14. Sharp MA. Physical Fitness, Physical Training and Occupational Performance of Men and Women in the US Army: A Review of Literature. Natick, MA: US Army Research Institute of Environmental Medicine; July 1993. Report No. TN93-7. Available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a266297.pdf. Accessed March 10, 2015.

15. Beutler A, Sarah J, Marshall S, Padua D, Boden B. Muscle strength and qualitative jump-landing differences in male and female military cadets: The jump-ACL study. *J Sports Sci Med*. 2009;8:663-671.

16. Niu W, Wang Y, He Y, Fan Y, Zhao Q. Biomechanical gender differences of the ankle joint during simulated half-squat parachute landing. *Aviat Space Environ Med*. 2010;81(8):761-767.

17. Abt J, Sell T, Crawford K, et al. Warior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part II. *J Spec Oper Med*. 2010;10(4):22-33.

18. Norkin CC, White DJ. *Measurement of Joint Motion: A Guide to Goniometry*. 3rd ed. Philadelphia, PA: FA Davis; 2003.

19. Myers JB, Oyama S, Wassinger CA, et al. Reliability, precision, accuracy, and validity of posterior shoulder tightness assessment in overhead athletes. *Am J Sports Med*. 2007;35(11):1922-1930.

20. Sell TC, Tsai Y-S, Smoliga JM, Myers JB, Lephart SM. Strength, flexibility, and balance characteristics of highly proficient golfers. *J Strength Cond Res*. 2007;21(4):1166-1171.

21. Crawford K, Fleishman K, Abt JP, et al. Less body fat improves physical and physiological performance in army soldiers. *Mil Med*. 2011;176(1):35-43.

22. Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active, young adults. *J Sport Rehabil*. 2008;17(2):160-170.

23. Spink M, Fotoohabadi M, Menz H. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. *Gerontology*. 2009.

24. Wang CY, Olson SL, Protas EJ. Test-retest strength reliability: hand-held dynamometry in community-dwelling elderly fallers. *Arch Phys Med Rehab*. 2002;83(6):811-815.

25. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: reliability and validity. *Arch Phys Med Rehab*. 1989;70(7):510-517.

26. Goldie PA, Evans OM, Bach TM. Steadiness in one-legged stance: development of a reliable force-platform testing procedure. *Arch Phys Med Rehabil*. 1992;73(4):348-354.

27. Sell TC, Ferris CM, Abt JP, et al. Predictors of proximal tibia anterior shear force during a vertical stop-jump. *J Orthop Res*. 2007;25(12):1589-1597.

28. Attinger A, Tuller C, Souren T, Tamm M, Schindler C, Brutsche MH. Feasibility of mobile cardiopulmonary exercise testing. *Swiss Med Wkly*. 2006;136(1-2):13-18.

29. Smith J, Hill D. Contribution of energy systems during a Wingate power test. *Br J Sports Med*. 1991;25(4):196-199.

30. Bar-Or O. The Wingate anaerobic test an update on methodology, reliability and validity. *Sports Med*. 1987;4(6):381-394.

31. Vescovi JD, Zimmerman SL, Miller WC, Hildebrandt L, Hammer RL, Fernhall B. Evaluation of the BOD POD for estimating percentage body fat in a heterogeneous group of adult humans. *Eur J Appl Physiol*. 2001;85(3-4):326-332.

32. Bell AL, Pedersen DR, Brand RA. A comparison of the accuracy of several hip center location prediction methods. *J Biomech*. 1990;23(6):617-621.

33. Davis III RB, Ounpuu S, Tyburski D, Gage JR. A gait analysis data collection and reduction technique. *Hum Mov Sci*. 1991;10(5):575-587.

34. Kadaba MP, Ramakrishnan H, Wootten M. Measurement of lower extremity kinematics during level walking. *J Orthop Res*. 1990;8(3):383-392.

35. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med*. 1999;27(5):585-593.

36. Pope R, Herbert R, Kirwan J. Effects of ankle dorsiflexion range and pre-exercise calf muscle stretching on injury risk in Army recruits. *Aust J Physiother*. 1998;44(3):165-172.

37. Witvrouw E, Bellemans J, Lysens R, Danneels L, Cambier D. Intrinsic risk factors for the development of patellar tendinitis in an athletic population. A two-year prospective study. *Am J Sports Med*. 2001;29(2):190-195.

38. Witvrouw E, Danneels L, Asselman P, D'Have T, Cambier D. Muscle flexibility as a risk factor for developing muscle injuries in male professional soccer players. A prospective study. *Am J Sports Med*. 2003;31(1):41-46.

39. Witvrouw E, Lysens R, Bellemans J, Cambier D, Vanderstraeten G. Intrinsic risk factors for the development of anterior knee pain in an athletic population. A two-year prospective study. *Am J Sports Med*. 2000;28(4):480-489.

40. Gabbe BJ, Bennell KL, Finch CF, Wajswelner H, Orchard JW. Predictors of hamstring injury at the elite level of Australian football. *Scand J Med Sci Sports*. 2006;16(1):7-13.

41. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *Am J Sports Med*. 1990;18(4):366-375.

42. Kraemer WJ, Mazzetti SA, Nindl BC, et al. Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc*. 2001;33(6):1011-1025.

43. Harman E, Frykman P, Palmer C, Lammi E, Reynolds K. *Effects of a Specifically Designed Physical Conditioning Program on the Load Carriage and Lifting Performance of Female Soldiers*. Natick, MA: US Army Research Institute of Environmental Medicine; November 1997. Report No. T98-1. Available at: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA333437. Accessed March 10, 2015.

44. Yeung SS, Suen AM, Yeung EW. A prospective cohort study of hamstring injuries in competitive sprinters: preseason muscle imbalance as a possible risk factor. *Br J Sports Med*. 2009;43(8):589-594.

45. Knapik JJ, Bauman CL, Jones BH, Harris JM, Vaughan L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J Sports Med*. 1991;19(1):76-81.

46. Arnold B, Linens S, Sarah J, Ross S. Concentric evertor strength differences and functional ankle instability: a meta-analysis. *J Athl Train*. 2009;44(6):653-662.

47. Baumhauer J, Alosa D, Renstrom P, Trevino S, Beynnon B. A prospective study of ankle injury risk factors. *Am J Sports Med*. 1995;23(5):564-570.

48. Pontaga I. Ankle joint evertor-invertor muscle torque ratio decrease due to recurrent lateral ligament sprains. *Clin Biomech (Bristol, Avon)*. 2004;19(7):760-762.

49. Willems T, Witvrouw E, Verstuyft J, Vaes P, De Clercq D. Proprioception and muscle strength in subjects with a history of ankle sprains and chronic instability. *J Athl Train*. 2002;37(4):487-493.

50. Lee JH, Ooi Y, Nakamura K. Measurement of muscle strength of the trunk and the lower extremities in subjects with history of low back pain. *Spine (Phila Pa 1976)*. 1995;20(18):1994-1996.

51. Mandell PJ, Weitz E, Bernstein JI, et al. Isokinetic trunk strength and lifting strength measures. Differences and similarities between low-back-injured and noninjured workers. *Spine (Phila Pa 1976)*. 1993;18(16):2491-2501.

52. McGuine TA, Greene JJ, Best T, Leverson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin J Sport Med*. 2000;10(4):239-244.

53. Trojian TH, McKeag DB. Single leg balance test to identify risk of ankle sprains. *Br J Sports Med*. 2006;40(7):610-613.

54. Wang HK, Chen CH, Shiang TY, Jan MH, Lin KH. Risk-factor analysis of high school basketball-player ankle injuries: A prospective controlled cohort study evaluating postural sway, ankle strength, and flexibility. *Arch Phys Med Rehabil*. 2006;87(6):821-825.

55. Wikstrom EA, Tillman MD, Kline KJ, Borsa PA. Gender and limb differences in dynamic postural stability during landing. *Clin J Sport Med*. 2006;16(4):311-315.

56. Wells CL. *Women, Sport, & Performance: A Physiological Perspective*. 2nd ed. Champaign, IL: Human Kinetics Books; 1991.

57. Fitzgerald PI, Vogel JA, Daniels WL, et al. *The Body Composition Project: A Summary Report and Descriptive Data*. Natick, MA: US Army Research Institute of Environmental Medicine; December 1986. Report No. T 5/87. Available at: http://www.dtic.mil/dtic/tr/fulltext/u2/a177679.pdf. Accessed March 10, 2015.

58. Teves MA, Vogel JA, Carlson DE, Schnakenberg DD. Body Composition and Muscle Performance Aspects of the 1985 CFFS Test. Natick, MA: US Army Research Institute of Environmental Medicine; April 1986. Report No. T12/86. Available at: http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA172752. Accessed March 10, 2015.

59. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for Plantar fasciitis: A matched case-control study. *J Bone Joint Surg Am*. 2003;85-A(5):872-877.

60. McHugh MP, Tyler TF, Tetro DT, Mullaney MJ, Nicholas SJ. Risk factors for noncontact ankle sprains in high school athletes: the role of hip strength and balance ability. *Am J Sports Med*. 2006;34(3):464-470.

61. Reynolds K, Cosio-Lima L, Bovill M, Tharion W, Williams J, Hodges T. A comparison of injuries, limited-duty days, and injury risk factors in infantry, artillery, construction engineers, and special forces soldiers. *Mil Med*. 2009;174(7):702-708.

62. Packnett ER, Niebuhr DW, Bedno SA, Cowan DN. Body mass index, medical qualification status, and discharge during the first year of US Army service. *Am J Clin Nutr*. 2011;93(3):608-614.

63. Benjaminse A, Habu A, Sell TC, et al. Fatigue alters lower extremity kinematics during a single-leg stop-jump task. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(4):400-407.

64. Rozzi SL, Lephart SM, Gear WS, Fu FH. Knee joint laxity and neuromuscular characteristics of male and female soccer and basketball players. *Am J Sports Med*. 1999;27(3):312-319.

65. Sell TC, Ferris CM, Abt JP, et al. The effect of direction and reaction on the neuromuscular and biomechanical characteristics of the knee during tasks that simulate the noncontact anterior cruciate ligament injury mechanism. *Am J Sports Med*. 2006;34(1):43-54.

66. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med*. 2005;33(4):492-501.

67. Boden BP, Torg JS, Knowles SB, Hewett TE. Video analysis of anterior cruciate ligament injury: abnormalities in hip and ankle kinematics. *Am J Sports Med*. 2009;37(2):252-259.

68. Jacobs CA, Uhl TL, Mattacola CG, Shapiro R, Rayens WS. Hip abductor function and lower extremity landing kinematics: sex differences. *J Athl Train*. 2007;42(1):76-83.

69. Kernozek TW, Torry MR, Iwasaki M. Gender differences in lower extremity landing mechanics caused by neuromuscular fatigue. *Am J Sports Med*. 2008;36(3):554-565.

70. Lephart SM, Abt JP, Ferris CM, et al. Neuromuscular and biomechanical characteristic changes in high school athletes: a plyometric versus basic resistance program. *Br J Sports Med*. 2005;39(12):932-938.

Authors

Dr Allison, Dr Keenan, Dr Sell, Dr Abt, Dr Nagai, and Ms Deluzio are with the Neuromuscular Research Laboratory of the Department of Sports Medicine and Nutrition, University of Pittsburgh, Pittsburgh, Pennsylvania.

COL McGrail is with the Blanchfield Army Community Hospital, Fort Campbell, Kentucky.

Dr Lephart is with the College of Health Sciences, University of Kentucky, Lexington, Kentucky.