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Effects of Deployment on Musculoskeletal and Physiological Characteristics and Balance

Takashi Nagai, PhD; John P. Abt, PhD†; Timothy C. Sell, PhD*; Karen A. Keenan, PhD*; COL Mark A. McGrail, MC USA‡; COL Brian W. Smalley, MC USA§; Scott M. Lephart, PhD†*

ABSTRACT Despite many nonbattle injuries reported during deployment, few studies have been conducted to evaluate the effects of deployment on musculoskeletal and physiological characteristics and balance. A total of 35 active duty U.S. Army Soldiers participated in laboratory testing before and after deployment to Afghanistan. The following measures were obtained for each Soldier: shoulder, trunk, hip, knee, and ankle strength and range of motion (ROM), balance, body composition, aerobic capacity, and anaerobic power/capacity. Additionally, Soldiers were asked about their physical activity and load carriage. Paired *t* tests or Wilcoxon tests with an $\alpha = 0.05$ set a priori were used for statistical analyses. Shoulder external rotation ROM, torso rotation ROM, ankle dorsiflexion ROM, torso rotation strength, and anaerobic power significantly increased following deployment ($p < 0.05$). Shoulder extension ROM, shoulder external rotation strength, and eyes-closed balance ($p < 0.05$) were significantly worse following deployment. The majority of Soldiers (85%) engaged in physical activity. In addition, 58% of Soldiers reported regularly carrying a load (22 kg average). The deployment-related changes in musculoskeletal and physiological characteristics and balance as well as physical activity and load carriage during deployment may assist with proper preparation with the intent to optimize tactical readiness and mitigate injury risk.

INTRODUCTION

It is estimated that 2.4 million U.S. military personnel deployed and served in Afghanistan and Iraq during the past decade.[1] About 35% and 20% of military personnel experienced at least one nonbattle injury during Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), respectively.[2,3] Of those Soldiers who sustained nonbattle injuries during OIF and OEF, 66% were placed on light duty for an average of 6 days and 5.4% were hospitalized for an average of 3 days.[2] Since foot patrol, lifting tasks, and sports were commonly associated with musculoskeletal injuries during deployment.[2,4] Physical fitness and physiological characteristics would likely play a role in unintentional musculoskeletal injuries.[5,6]

Previously, a decrease in aerobic capacity and increase in strength and power have been reported after deployment.[7–9] The authors concluded that a significant reduction in aerobic capacity might be explained by a significant reduction in the frequency and duration of aerobic training during deployment.[9] Lester et al[8] reported that over 60% of Soldiers performed job-related lifting over 12.5 kg at least 5 d/wk while 70% of Soldiers performed no job-related running. The authors suggested that job-related lifting and running and physical training in Iraq would explain the deployment-related changes in 2-mile run, strength, and power. Understanding Soldiers' load carriage and physical activity would likely help to explain deployment-related changes on musculoskeletal and physiological characteristics.

The purpose of the current investigation is to determine the effects of deployment to Afghanistan on musculoskeletal and physiological characteristics and balance and to survey Soldiers about physical activity and load carriage. Since balance and flexibility play an important role in musculoskeletal injury prevention[5,6] and deployment-related changes on balance and flexibility are largely unknown, these variables were included in the current investigation. According to the previous findings, it was hypothesized that aerobic capacity and body fat (BF) would worsen over the course of deployment while strength and power would improve. Additionally, it was hypothesized that flexibility and balance would also worsen over the course of deployment. Clinically, it is important to understand deployment-related changes so that Soldiers can better prepare for deployment and sustain musculoskeletal, physiological, and balance capabilities during deployment to mitigate risk for injury and to maintain tactical readiness.

METHODS

Participants

A total of 35 active duty Soldiers from the U.S. Army 101st Airborne Division (Air Assault) in Fort Campbell,

*Neuromuscular Research Laboratory, Warrior Human Performance Research Center, Department of Sports Medicine and Nutrition, University of Pittsburgh, 3830 South Water Street, Pittsburgh, PA 15203.

†Sports Medicine Research Institute, College of Health Sciences, University of Kentucky, 900 South Limestone Street, Lexington, KY 40536.

‡Blanchfield Army Community Hospital, 650 Joel Drive, Fort Campbell, KY 42223.

§U.S. Army Aeromedical Activity, 301 Dustoff Road, Fort Rucker, AL 36362.

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TABLE I. Demographic Characteristics

Demographics (30 Males/5 Females)	Pre Mean ± SD	Post Mean ± SD	*p* Value	Effect Size	Power
Age (years)*	24.8 ± 4.9	26.5 ± 4.9	0.001	3.469	1.000
Height (cm)	174.4 ± 8.6	174.3 ± 8.5	0.216	0.181	0.181
Mass (kg)	76.6 ± 13.7	76.7 ± 14.3	0.961	0.019	0.051

*Statistically significant difference ($p < 0.05$).

Kentucky, volunteered to participate. Inclusion criteria were age 18 to 55 years; no concussion or mild head injury in the past year; no neurological/balance disorders; and no spinal, upper limb, or lower limb impairment that could affect test performance. All subjects were cleared for active duty without any injury profile prescribed throughout the study period or within the 3 months before enrollment. Exclusion criteria were cardiovascular, pulmonary, or metabolic disorder or skin allergy to adhesive tape. A written informed consent was obtained from each subject before their participation. Soldiers from various military specialty occupations participated in the study. On average, on the basis of their occupational physical demand rating (1 = light, 2 = medium, 3 = moderately heavy, 4 = heavy, and 5 = very heavy), most Soldiers were from moderate to very heavy military specialty occupations (physical demand rating: 3.9 ± 1.2). Demographic data are listed in Table I. Human subject protections approvals were obtained from the University of Pittsburgh and Dwight D. Eisenhower Army Medical Center. All tests were performed in the Human Performance Research Center at Fort Campbell. Predeployment tests were conducted during the individual training phase (6–9 months before deployment). Postdeployment tests were conducted upon their return from Afghanistan (within 3 months).

Instrumentation

A digital inclinometer (Saunders Group, Chaska, Minnesota) was used for all range of motion (ROM) tests except trunk rotation. The inclinometer has a resolution of 1° and accuracy of ±1° according to the manufacturer's manual. The Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Shirley, New York) was used to assess trunk rotation ROM and for all strength tests, except ankle inversion and eversion. This instrumentation has been reported to have excellent reliability and precision for both trial-to-trial and day-to-day for position (intraclass correlation coefficient [ICC] > 0.99, standard error of measurement [SEM] = 0.45–0.60°) as well as for trial-to-trial for torque (ICC > 0.99, SEM = 0.00–0.39 N·m).[10] A handheld dynamometer (Lafayette Instrument Company, Lafayette, Indiana) was used to test ankle inversion and eversion strength. The accuracy and resolution of the dynamometer are ±1.36kg and 0.2 kg, respectively, according to the manufacturer's manual. Three-dimensional ground reaction forces (GRF) were collected with a single force plate (Kistler 9286A; Kistler Instrument Corporation, Amherst, New York) at a sampling frequency of 200 Hz to assess balance.

Anaerobic power and capacity were measured utilizing an electromagnetic cycling ergometer (RacerMate, Seattle, Washington). According to the manufacturer, this system is both reliable (±0.2% or better) and accurate (±1.5%). Aerobic capacity was measured utilizing a portable metabolic system (OxyCon Mobile; Viasys, Yorba Linda, California) during a maximal oxygen uptake (VO_{2max}) test. This system has been proven valid and accurate as compared to the Douglas bag method.[11] A heart rate monitor (Polar USA, Lake Success, New York) was worn by the subject during testing and a portable lactate analyzer (Arkray, Kyoto, Japan) was used to assess blood lactate levels. The lactate analyzer has high precision according to the manufacturer (coefficient of variation = 3%). Body composition was assessed with The BodPod Body Composition System (Life Measurement Instruments, Concord, California) through air displacement plethysmography. This system has been demonstrated to be valid as compared to hydrostatic weighing and has demonstrated excellent reliability and accuracy (ICC = 0.99, coefficient of variation = 3.4%).[12]

Procedures

Flexibility, strength, and balance tests were performed on the dominant leg and arm, which were operationally defined as the preferred leg to kick a ball and the preferred arm to throw a ball, respectively. Trunk rotation flexibility and strength tests were performed in both the right and left directions. Passive shoulder extension, internal rotation (IR), and external rotation (ER) ROM were measured using the methods described by Norkin and White.[13] Posterior shoulder tightness was measured in a supine position based on the description by Tyler et al.[14,15] Active ROM assessments included the active knee extension test,[16] ankle dorsiflexion in a short sitting position, and torso rotation in a seated position.[17] All ROM measures were presented as an average of three trials. These procedures have been demonstrated to have excellent reliability and precision in our laboratory (ICC > 0.824, SEM < 4.59°).[17]

The following strength measures were assessed: shoulder IR and ER, hip abduction, knee flexion/extension, and torso rotation. The subjects were provided verbal instructions for completing each strength test and stabilized according to the manufacturer's instructions to avoid accessory motion.

For the shoulder, knee, and torso, subjects were given three submaximal practice trials at 50% effort followed by three maximal practice trials for familiarization. A rest period of at least 60 seconds was given following these practice trials before each strength test. For the shoulder, knee, and torso, five repetitions of reciprocal concentric/concentric isokinetic tests were performed. Isometric hip abduction strength was tested in the side-lying position with the hip in 20° abduction. After three submaximal practice trials, subjects performed three maximal contractions against the stationary dynamometer attachment for 5 seconds followed by 10 seconds of rest. Isometric ankle inversion/eversion tests were performed in a long-seated position with the feet just off of the table using manual resistance and stabilization. After three submaximal practice trials, subjects were asked to maximally move their foot in (inversion) or out (eversion) against the handheld dynamometer for 5 seconds. A total of three repetitions for each direction, with 10 seconds of rest between each repetition, were performed. These procedures have been demonstrated to have good-to-excellent reliability and precision in our laboratory (ICC > 0.784, SEM < 14.8%).[17]

Balance testing was assessed utilizing procedures established in our laboratory.[5,17,18] Subjects performed a single-leg standing balance test (barefooted) for 10 seconds under eyes-open and eyes-closed conditions. Subjects were asked to remain as still as possible with opposite leg raised to about the level of the tested ankle without touching the tested limb and with hands on their hips. If subjects happened to lose balance, trials were repeated. These procedures have been demonstrated to have good-to-excellent reliability and precision in our laboratory (ICC > 0.71, SEM < 3.40).[17,18]

Anaerobic power and capacity were measured utilizing the Wingate protocol. Proper seat and handlebar adjustments were made before the subject's feet were secured to the pedals, after which a warm-up was initiated at 125 W and 100 rpm. The test began with 15 seconds of cycling at the warm-up speed, followed by a 5-second sprint to generate as much speed as possible, after which a normalized resistance was initiated. The subject continued to sprint and maintain as much speed as possible against the resistance during the remaining 30 seconds of the test. Previous research has reported good-to-excellent reliability for these procedures ($r > 0.70$).[19]

Aerobic capacity was measured utilizing an incremental ramped treadmill protocol,[5] which consisted of a 5-minute warm-up period, an initial 3-minute workload at 0% grade, and an incline increase of 2.5% every 3 minutes although the speed remained constant. The treadmill speed was normalized to 70% of the subjects' 2-mile run times during their most recent Army Physical Fitness Test. Subjects were instructed to continue running until they could not continue to run (volitional fatigue). Oxygen uptake (VO_2) was monitored continuously throughout the test, and a blood sample was taken via finger prick at the end of each stage before the incline was increased.

Body composition was assessed through air displacement plethysmography. Standard calibration utilizing a 50.683-L calibration cylinder and an additional 2-point calibration was performed before each test. Subjects wore spandex shorts (and sport bra for females) and a swim cap. Body volume was measured until two consistent measurements were achieved. This procedure has been demonstrated to have excellent reliability and precision in our laboratory (ICC = 0.98, SEM = 0.47% BF).[20]

The deployment survey was to ask Soldiers about their experiences on physical activity and load carriage during deployment. If Soldiers answered "yes" on the first question, "engaged in physical activities regularly?," then, the following questions were asked: frequency of physical activities, duration of each physical activity session, and which facilities used. If Soldiers answered "yes" on the second question, "load carriage regularly?," then, the following questions were asked: self-reported weight of load, a frequency of load carriage, and duration of load carriage on average.

Data Reduction

For all ROM measurements, the average of three trials was used in data analysis. The average peak torque across five trials was calculated for all strength measurements except for hip abduction and ankle inversion/eversion, which were calculated across three trials. All strength measures were normalized to percentage of body mass (%BM). GRF data from the balance assessments were processed using a custom MATLAB (v7.0.4; The MathWorks, Natick, Massachusetts) script. Data were filtered using a zero-lag 4th-order Butterworth filter (cutoff frequency of 20 Hz). The standard deviation (SD) of the GRF for each direction (anterior–posterior [AP], medial–lateral [ML], and vertical) was calculated during the 10-second balance trial and then averaged across three trials for each condition. Anaerobic power was reported as the peak watts normalized to BM (W/kg) produced during the first 5 seconds of the test. Anaerobic capacity was reported as the average peak watts normalized to BM (W/kg) during the entire test. Both measures were automatically calculated by the software. The following physiological variables were utilized to verify a maximal aerobic test: reaching/exceeding age-predicted maximum heart rate, plateau of absolute VO_2 as exercise intensity increased, blood lactate reaching/exceeding 8 mmol/L, respiratory exchange ratio reaching/exceeding 1.1, or volitional fatigue. The metabolic data were filtered with a 30-second moving window to reduce variability of breath-by-breath data points. Data were plotted (VO_2 vs. time), and highest consecutive values over a 1-minute period were identified and averaged. The VO_{2max} was reported in milliliters of oxygen uptake per BM per minute (mL/kg/min). Predicted lung volume and an appropriate densitometry equation were used to calculate BF percentage (%BF).[21]

Statistical Analysis

For survey data, a frequency and proportion on "yes" and "no" questions were calculated by hand. Means and SDs were calculated on a frequency and duration of physical activity and load carriage using SPSS 17.0 (SPSS, Chicago, Illinois). All statistical analyses of musculoskeletal and physiological characteristics and balance were performed using the same software. Descriptive statistics (means and SDs) were calculated first. After assessing data for the assumptions of normality and equal variance, comparisons between pre- and post-deployment were performed utilizing paired t tests or Wilcoxon tests with an $\alpha = 0.05$ set a priori. Effect size and statistical power were calculated for each variable.

RESULTS

The average number of days between pre-deployment testing and deployment, of deployment to Afghanistan, and between return from deployment and post-deployment testing are listed in Table II. Flexibility, strength, balance, and physiology data are presented in Tables III-VI, respectively. Shoulder extension ROM significantly decreased post-deployment (pre: 81.0 ± 9.6°, post: 76.8 ± 10.6°, $p = 0.004$) whereas shoulder ER (pre: 113.0 ± 8.1°, post: 116.3 ± 11.6°, $p = 0.013$), trunk left rotation (pre: 64.6 ± 11.9°, post: 70.7 ± 10.2°, $p = 0.006$), and ankle dorsiflexion ROM (pre: 15.0 ± 4.3°, post: 20.3 ± 7.2°, $p = 0.001$) significantly increased post-deployment. Significant changes were also demonstrated in shoulder ER and left trunk rotation strength ($p < 0.05$). Specifically, shoulder ER (pre: 43.9 ± 10.8 %BM, post: 40.9 ± 9.2 %BM, $p = 0.034$) significantly decreased post-deployment whereas right (pre: 129.4 ± 37.2 %BM, $p = 0.001$) and left trunk rotation strength (pre: 130.8 ± 37.2 %BM, post: 153.2 ± 42.2 %BM, $p = 0.001$) significantly increased post-deployment. For the balance variables, the ML direction during a single-leg stance with eyes-closed significantly increased post-deployment (pre: 7.86 ± 3.62 N, post: 9.68 ± 5.78 N, $p = 0.032$). Peak anaerobic power significantly increased post-deployment (pre: 11.7 ± 2.5 W/kg, post: 12.5 ± 2.6 W/kg, $p = 0.019$). There were no other significant differences in the other dependent variables. The survey results are listed in Table VII.

TABLE II. Descriptive Statistics on Deployment Length and Test Interval (in Days)

Deployment Length/Test Interval	Mean ± SD
Predeployment Test to Deployment	207.3 ± 76.2
Deployment Length	350.5 ± 17.9
Return to Postdeployment Test	23.2 ± 22.2

DISCUSSION

The purpose of the current investigation was to evaluate the changes in musculoskeletal and physiological characteristics as well as balance following deployment to Afghanistan. In addition, Soldiers' physical activity and load carriage in Afghanistan were investigated. It was hypothesized that aerobic capacity, BF, flexibility, and balance would worsen over the course of the deployment while strength and power would improve. The results were mixed, and the hypotheses were partially supported. On the basis of the current results, strategies for injury prevention and tactical readiness before and during deployment are discussed.

The physical activity survey revealed that a majority of Soldiers continued their physical activity regularly while deployed. Sharp et al[9] reported that 87% of Soldiers were engaged in aerobic training while 93.5% were engaged in strength training during deployment. Similarly, the results from the current survey indicated that 82.1% of Soldiers engaged in cardiovascular training and 85.7% were engaged in resistance training. There was a large difference in sports participation. In the current study, only 7.1% of Soldiers participated in sports activities whereas Sharp et al[9] reported 60.2% of Soldiers participated in sports activities. This difference in the rate of sports participation may be attributable to differences in units. The Soldiers in the current study were from the combat aviation support battalion from the 101st Airborne Division (Air Assault) (deployed to Afghanistan in late 2008 to late 2009) while the Soldiers in the study by Sharp et al[9] were from infantry battalion from the 10th Mountain Division (deployed to Afghanistan in early to late 2006). In addition, military occupational

TABLE III. Descriptive Statistics for Flexibility/ROM Characteristics (in Degrees)

Flexibility Variable	Pre Mean ± SD	Post Mean ± SD	p Value	Effect Size	Power
Shoulder Extension*	81.0 ± 9.6	76.8 ± 10.6	0.004	0.492	0.807
Shoulder IR	56.2 ± 8.3	56.9 ± 11.7	0.588	0.084	0.077
Shoulder ER*	113.0 ± 10.5	116.3 ± 11.6	0.013	0.454	0.742
Posterior Shoulder Tightness	103.1 ± 8.1	99.7 ± 15.9	0.206	0.216	0.237
Torso Right Rotation	69.9 ± 11.4	72.4 ± 8.3	0.316	0.188	0.191
Torso Left Rotation*	64.6 ± 11.9	70.7 ± 10.2	0.006	0.479	0.786
Straight Leg Raise	18.0 ± 10.3	15.9 ± 9.5	0.138	0.279	0.361
Ankle Dorsiflexion*	15.0 ± 4.3	20.3 ± 7.2	0.001	0.821	0.997

*Statistically significant difference ($p < 0.05$).

TABLE IV. Descriptive Statistics of Strength Characteristics

Strength Variable	Pre Mean ± SD	Post Mean ± SD	p Value	Effect Size	Power
Shoulder IR (%BM)	59.7 ± 17.7	59.9 ± 18.4	0.932	0.018	0.051
Shoulder ER (%BM)*	43.9 ± 10.8	40.9 ± 9.2	0.034	0.396	0.624
Shoulder ER/IR Ratio	0.76 ± 0.13	0.72 ± 0.18	0.234	0.225	0.253
Trunk Rotation Right (%BM)*	129.4 ± 37.2	155.8 ± 40.9	0.001	1.222	0.999
Trunk Rotation Left (%BM)*	130.8 ± 37.2	153.2 ± 42.2	0.001	0.732	0.988
Trunk Rotation Right/Left Ratio	0.99 ± 0.09	1.03 ± 0.12	0.160	0.284	0.372
Hip Abduction (%BM)	166.4 ± 31.3	164.9 ± 31.3	0.773	0.054	0.061
Knee Flexion (%BM)	114.0 ± 31.5	118.2 ± 24.7	0.266	0.203	0.215
Knee Extension (%BM)	239.9 ± 60.9	234.3 ± 47.4	0.427	0.137	0.124
Knee Flexion/Extension Ratio	0.48 ± 0.12	0.51 ± 0.08	0.218	0.240	0.281
Ankle Inversion (%BM)	46.3 ± 10.6	46.6 ± 9.2	0.816	0.031	0.054
Ankle Eversion (%BM)	43.6 ± 10.8	42.2 ± 9.2	0.495	0.176	0.174
Ankle Inversion/Eversion Ratio	0.93 ± 0.11	0.91 ± 0.12	0.169	0.145	0.132

*Statistically significant difference ($p < 0.05$).

TABLE V. Descriptive Statistics of Balance Characteristics (in Newtons)

Balance Variable (SDs of GRF)	Pre Mean ± SD	Post Mean ± SD	p Value	Effect Size	Power
Eyes-Open AP	2.53 ± 0.53	2.52 ± 0.51	0.920	0.023	0.052
Eyes-Open ML	3.01 ± 0.94	3.10 ± 0.96	0.666	0.082	0.076
Eyes-Open Vertical	4.05 ± 1.52	4.58 ± 2.13	0.357	0.204	0.216
Eyes-Closed AP	5.56 ± 2.13	5.93 ± 3.07	0.483	0.125	0.111
Eyes-Closed ML*	7.86 ± 3.62	9.68 ± 5.78	0.032	0.388	0.607
Eyes-Closed Vertical	10.40 ± 4.36	13.45 ± 10.12	0.096	0.305	0.418

*Statistically significant difference ($p < 0.05$).

TABLE VI. Descriptive Statistics of Physiological Characteristics

Physiological Variable	Pre Mean ± SD	Post Mean ± SD	p Value	Effect Size	Power
%BF	19.9 ± 8.0	19.5 ± 7.5	0.643	0.079	0.074
Anaerobic Power (W/kg)*	11.7 ± 2.5	12.5 ± 2.6	0.019	0.442	0.720
Anaerobic Capacity (W/kg)	7.5 ± 0.9	7.2 ± 0.9	0.060	0.490	0.805
VO_{2max} (mL/kg/min)	46.9 ± 6.6	45.8 ± 7.0	0.353	0.185	0.186

*Represents significant difference ($p < 0.05$).

specialties, deployment locations within Afghanistan, and tactical strategies might differ between the subjects in the two studies.

The current study described Soldiers' load carriage during deployment. On average, Soldiers reported a carriage load of 22 kg. A previous report indicated that an average fighting load/equipment was 29 to 32 kg in an Infantry unit in Afghanistan.[22,23] As with physical activity, these differences may be related to unit differences, military occupational specialties, deployment locations within Afghanistan, and tactical strategies. Carrying a load over a period might have deteriorating effects on joints. Sell et al[24] reported that additional load of combat gear (a total of 15 kg) influenced landing mechanics with increased maximum GRF, maximum knee flexion angle, and time to reach maximum GRF and knee flexion angle. Similarly, Attwells et al[25] reported that walking with a load could increase trunk lean and knee joint angle. Heller et al[26] reported that a load of 18 kg increased postural sway. It is likely important to introduce exercises with load early before deployment to minimize the influence of load carriage during deployment.

Flexibility

Shoulder extension ROM significantly decreased post-deployment while shoulder ER, torso rotation, and ankle dorsiflexion ROM significantly increased. Decreased shoulder extension ROM may be related to the stress placed on the shoulder by combat loads. A recent survey revealed that wearing the individual body armor (IBA) was the most

TABLE VII. Deployment Physical Activity Survey Results

Physical Activity Description	
Engaged in Physical Activities Regularly?	Yes: 28 (84.9%); No: 5 (15.1%)
Frequency per Week (Days)	4.6 ± 1.5
Duration of Physical Activities (minute)	66.8 ± 26.2
Facilities Used (Gym/Outside)	Gym: 28/28, Outside: 2/28
Types of Physical Activities	
Resistance Type	Yes: 24 (85.7%); No: 4 (14.3%)
Cardiovascular Type	Yes: 23 (82.1%); No: 5 (17.9%)
Both Types	Yes: 20 (71.4%); No: 8 (28.6%)
Sports	Yes: 2 (7.1%); No: 26 (92.9%)
Load Carriage Description	
Load Carriage Regularly?	Yes: 19 (57.6%); No: 14 (42.4%)
Self-reported Weight of Load (kg)	22.2 ± 9.6
Frequency of Load Carriage per Week (Days)	3.7 ± 2.3
Duration of Load Carriage per Day (hours)	3.5 ± 2.2

common aggravating factor of upper extremity musculoskeletal pain during deployment to Iraq.[27] If wearing the IBA contributes to upper extremity musculoskeletal pain, it is plausible that Soldiers may decrease ROM in an attempt to avoid painful arcs of motion. Another potential explanation is that a prolonged forward shoulder/rounded shoulder posture when carrying a load may lead to shortening of the anterior shoulder muscles which may lead to a decrease in extension. Although the current results cannot confirm whether load carriage decreases shoulder extension ROM, future studies should investigate the relationship between load carriage and shoulder ROM.

Subjects demonstrated a significant increase in left trunk rotation ROM but no change in right rotation ROM post-deployment. It is interesting to note that the gain in left rotation ROM post-deployment appears to offset the imbalance between right and left rotation ROM pre-deployment. On the basis of the trunk rotation ROM gain in the current study, it is speculated that Soldiers perform carrying or lifting tasks using a full range of trunk rotation motion or engage in stretching exercises.

Ankle dorsiflexion ROM significantly increased post-deployment. Ankle dorsiflexion play an important role in preventing ankle inversion sprains. It is not clear what caused the calf muscles to be stretched during deployment. A possible explanation is based on a combination of load carriage and a use of boots. A recent gait study reported increased ankle dorsiflexion ROM when subjects carried military load and walked in boots.[28] The authors also reported increased hip and knee flexion angles in an attempt to absorb extra weight.[28] Soldiers in Afghanistan wear boots constantly while carrying military load. The survey results indicate that Soldiers carried load on 3.7 d/wk for 3.5 h/d on average.

Strength

Shoulder ER strength significantly decreased post-deployment. Although the causes of reduction in shoulder ER strength are largely unknown, there are possible explanations. First, cases for brachial plexus injuries caused by prolonged wear of IBA were reported previously.[29] Although there are few recent studies on IBA and brachial plexus injuries, it is possible that shoulder weakness could be caused by pain or nerve injuries from wearing IBA.[27] Second, in the current survey, over 85% of Soldiers participated in resistance training. However, it is unknown what exercises they did for upper extremity. It is possible that fewer Soldiers have engaged in the upper extremity exercises during deployment. Through a personal communication, the Division Surgeon mentioned that many male Soldiers try to increase bench press and develop shoulder pain and issues. Since there are many types of innovative equipment and commercially available training programs, it is important to expand the current survey and capture the details about equipment and training. In return, those details might help to further explain the current findings. It is important to take care of the shoulder from unnecessary musculoskeletal injuries and establish preventable strategies. The shoulder was one of most frequently injured locations among nonbattle injuries during OIF.[30,31] In a civilian study, individuals with shoulder impingement and instability demonstrate a reduction in shoulder IR and ER strength.[32] A cadaveric study indicated the ER muscle group (infraspinatus/teres minor) is the most effective in providing dynamic stability opposing anterior translation of the humeral head.[33,34] Therefore, decreased ER strength may compromise dynamic stability and increase susceptibility for injury.

Trunk rotation strength significantly increased post-deployment. In civilian studies, decreased trunk ROM and strength are reported in individuals with lower back pain.[35,36] If back pain is not well managed, it has long-lasting impact on force readiness. It is reported that the majority of nonbattle injuries during deployment involve the lower back, ankle, knee, and shoulder.[3,31] A recent military study indicated that Soldiers who were medically evacuated out of theater because of back pain have a very low rate of return to unit (13%).[37] Soldiers may benefit from strengthening the trunk musculature, particularly in preparation for deployment.

The current results indicate no significant changes in hip, knee, and ankle strength. It is not clear why trunk strength was significantly increased while hip, knee, and ankle strength did not change. Despite a lack of significant changes, hip strength, knee strength, and knee flexion/extension strength ratio are important variables to continue evaluating Soldiers. In a civilian study, increased hip abduction, knee flexion, and knee extension strength were correlated with less knee valgus angles during a single-leg squat.[38] Another study indicated that lower knee flexion/extension strength ratio was associated with female athletes who later suffered noncontact anterior cruciate ligament injuries.[39]

Balance

Eyes-closed ML balance was significantly worse post-deployment. Because of no change on eyes-open ML balance, it is speculated that Soldiers rely on the visual system to maintain their balance in the ML direction. Poor balance is identified as an intrinsic risk factor for ankle injuries.[40] On the basis of the current results, it is clinically essential to detect balance early so that a proper intervention can be administered. Recently, balance exercises were incorporated within the comprehensive training program for Soldiers of the 101st Airborne Division (Air Assault) and resulted in improved static and dynamic balance in Soldiers.[6]

Physiological Characteristics

Peak anaerobic power increased significantly post-deployment. This is in agreement with previous research that reported increases in muscular power after deployment.[8,9] In the current investigation, an increase in anaerobic power was likely related to load carriage and resistance training during deployment. On the basis of the survey results, over 85% of Soldiers engaged in resistance training during deployment. In addition, carrying load (average 22 kg) for 3.5 h/d for 3.7 d/wk during deployment (350 days) would likely provide sufficient stimuli for a development of muscular strength and power. From a force readiness perspective, more focused exercises to improve anaerobic power should be incorporated in physical training before deployment.

There were no significant changes in %BF and VO_{2max}. In contrast, previous studies reported that %BF and VO_{2max} worsened after deployment to Iraq and/or Afghanistan.[8,9] It could be explained by differences in a percent of Soldiers who engaged in aerobic training. In the current study, 82.1% of Soldiers reported participating in cardiovascular training while deployed. Contrarily, Sharp et al[9] reported that nearly 50% of Soldiers engaged in aerobic training once a week or less during a deployment to Afghanistan in 2006. In addition, the current investigation took place in 2008–2009, thus mission and operation demands as well as available physical training facilities may have varied between investigations. Another potential explanation is a role of high altitude in Afghanistan. A combination of physical training and physical demand of mission in high altitude might have contributed to the sustainment of the aerobic capacity and body composition.

There are limitations to the current study. Observed changes in physical and physiological characteristics could also be influenced by other factors (physical demand of missions, location/environment of forward operating bases, and proper nutrition). Additionally, the current study did not have a control group without deployment to evaluate what the natural aging does to their body, physical, and physiological characteristics. Future studies should incorporate questions regarding these factors. Another limitation is that injuries were not tracked in the periods pre-, during, and post-deployment; therefore, we do not really know how these changes are related to risk of injury. It is suggested that future investigations track such external factors and nonbattle musculoskeletal injuries and identify their contributions to physiologic and musculoskeletal characteristics and balance changes throughout a deployment cycle and how those changes are related to risk of injury. Finally, the population and deployment cycle/location/mission types were specific and unique to the current study. Implications and generalization to other units and deployment cycle/location might be limited. Continued efforts to investigate effects of deployment on various units and deployment cycle/location/mission types were warranted.

In conclusion, the current investigation revealed deployment-related changes in various musculoskeletal and physiological characteristics and balance. In most cases, Soldiers can address the observed changes by engaging in specific exercises before deployment. In addition, a maintenance program should be implemented for Soldiers to keep their physical fitness with minimal equipment and limited space. Effect of pre-, during, and post-deployment training can be evaluated in a future longitudinal study.

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REFERENCES

1. Spelman JF, Hunt SC, Seal KH, Burgo-Black AL: Post deployment care for returning combat veterans. J Gen Intern Med 2012; 27(9): 1200–9.
2. 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): 1256–62.
3. Sanders JW, Putnam SD, Frankart C, et al: Impact of illness and non-combat injury during Operations Iraqi Freedom and Enduring Freedom (Afghanistan). Am J Trop Med Hyg 2005; 73(4): 713–9.
4. Roy TC, Ritland BM, Knapik JJ, Sharp MA: Lifting tasks are associated with injuries during the early portion of a deployment to Afghanistan. Mil Med 2012; 177(6): 716–22.
5. Sell TC, Abt JP, 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.
6. Abt JP, Sell TC, Crawford K, et al: Warrior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part II. J Spec Oper Med 2010; 10(4): 22–33.
7. Knapik JJ, Spiess A, Grier TL, et al: Injuries and Physical Fitness Before and After Deployments of the 10th Mountain Division to Afghanistan and the 1st Cavalry Division to Iraq. Defense Technical Information Center Web site; 2008. Available at http://www.dtic.mil/dtic/tr/fulltext/u2/a496351.pdf; accessed June 3, 2015.
8. Lester ME, Knapik JJ, Catrambone D, et al: Effect of a 13-month deployment to Iraq on physical fitness and body composition. Mil Med 2010; 175(6): 417–23.
9. Sharp MA, Knapik JJ, Walker LA, et al: Physical fitness and body composition after a 9-month deployment to Afghanistan. Med Sci Sports Exerc 2008; 40(9): 1687–92.

10. Drouin JM, Valovich-McLeod TC, Shultz SJ, Gansneder BM, Perrin DH: Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. Eur J Appl Physiol 2004; 91(1): 22–9.
11. Rosdahl H, Gullstrand L, Salier-Eriksson J, Johansson P, Schantz P: Evaluation of the Oxycon Mobile metabolic system against the Douglas bag method. Eur J Appl Physiol 2010; 109(2): 159–71.
12. 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): 326–32.
13. Norkin CC, White DJ: Measurement of Joint Motion: A Guide to Goniometry, Ed 2. Philadelphia, PA, F.A. Davis Company, 1995.
14. Tyler TF, Nicholas SJ, Roy T, Gleim GW: Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. Am J Sports Med 2000; 28(5): 668–73.
15. Tyler TF, Roy T, Nicholas SJ, Gleim GW: Reliability and validity of a new method of measuring posterior shoulder tightness. J Orthop Sports Phys Ther 1999; 29(5): 262–9; discussion 270–4.
16. Gajdosik R, Lusin G: Hamstring muscle tightness. Reliability of an active-knee-extension test. Phys Ther 1983; 63(7): 1085–90.
17. Sell TC, Tsai YS, Smoliga JM, Myers JB, Lephart SM: Strength, flexibility, and balance characteristics of highly proficient golfers. J Strength Cond Res 2007; 21(4): 1166–71.
18. Sell TC, House AJ, Huang HC, Abt JP, Lephart SM: An examination, correlation, and comparison of static and dynamic measures of postural stability in healthy, physically active adults. Phys Ther Sport 2012; 13(2): 80–6.
19. Astorino TA, Cottrell T: Reliability and validity of the Velotron Racermate cycle ergometer to measure anaerobic power. Int J Sports Med 2012; 33(3): 205–10.
20. 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.
21. Siri WE: Body composition from fluid space and density. In: Techniques for Measuring Body Composition, pp 223–44. Edited by Brozek J, Hanschel A. Washington, DC, National Academy of Science, 1961.
22. Roy TC, Lopez HP: A comparison of deployed occupational tasks performed by different types of military battalions and resulting low back pain. Mil Med 2013; 178(8): e937–43.
23. Dean C: The Modern Warrior's Combat Load: Dismounted Operations in Afghanistan April - May 2003. Center for Army Lessons Learned Web site. 2003. Available at https://call2.army.mil/CallSearch/isysquery/966b6712-ceab-4767-9488-d2bc15a2d7fe/3/doc/; accessed September 28, 2015.
24. Sell TC, Chu Y, Abt JP, et al: Minimal additional weight of combat equipment alters air assault soldiers' landing biomechanics. Mil Med 2010; 175(1): 41–7.
25. Attwells RL, Birrell SA, Hooper RH, Mansfield NJ: Influence of carrying heavy loads on soldiers' posture, movements and gait. Ergonomics 2006; 49(14): 1527–37.
26. Heller MF, Challis JH, Sharkey NA: Changes in postural sway as a consequence of wearing a military backpack. Gait Posture 2009; 30(1): 115–7.
27. Konitzer LN, Fargo MV, Brininger TL, Lim Reed M: Association between back, neck, and upper extremity musculoskeletal pain and the individual body armor. J Hand Ther 2008; 21(2): 143–8; quiz 9.
28. Majumdar D, Pal MS, Majumdar D: Effects of military load carriage on kinematics of gait. Ergonomics 2010; 53(6): 782–91.
29. Bhatt BM: "Top cover neuropathy"—transient brachial plexopathy due to body armour. J R Army Med Corps 1990; 136(1): 53–4.
30. Owens BD, Dawson L, Burks R, Cameron KL: Incidence of shoulder dislocation in the United States military: demographic considerations from a high-risk population. J Bone Joint Surg Am 2009; 91(4): 791–6.
31. Belmont PJ Jr, Goodman GP, Waterman B, DeZee K, Burks R, Owens BD: Disease and nonbattle injuries sustained by a U.S. Army Brigade Combat Team during Operation Iraqi Freedom. Mil Med 2010; 175(7): 469–76.
32. 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): 366–75.
33. Lee SB, Kim KJ, O'Driscoll SW, Morrey BF, An KN: Dynamic glenohumeral stability provided by the rotator cuff muscles in the mid-range and end-range of motion. A study in cadavera. J Bone Joint Surg Am 2000; 82(6): 849–57.
34. Cain PR, Mutschler TA, Fu FH, Lee SK: Anterior stability of the glenohumeral joint. A dynamic model. Am J Sports Med 1987; 15(2): 144–8.
35. Mayer TG, Tencer AF, Kristoferson S, Mooney V: Use of noninvasive techniques for quantification of spinal range-of-motion in normal subjects and chronic low-back dysfunction patients. Spine 1984; 9(6): 588–95.
36. Tsai YS, Sell TC, Smoliga JM, Myers JB, Learman KE, Lephart SM: A comparison of physical characteristics and swing mechanics between golfers with and without a history of low back pain. J Orthop Sports Phys Ther 2010; 40(7): 430–8.
37. Cohen SP, Nguyen C, Kapoor SG, et al: Back pain during war: an analysis of factors affecting outcome. Arch Intern Med 2009; 169(20): 1916–23.
38. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM: Relationship between hip and knee strength and knee valgus during a single leg squat. J Appl Biomech 2006; 22(1): 41–50.
39. Myer GD, Ford KR, Barber Foss KD, Liu C, Nick TG, Hewett TE: The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. Clin J Sport Med 2009; 19(1): 3–8.
40. Witchalls J, Blanch P, Waddington G, Adams R: Intrinsic functional deficits associated with increased risk of ankle injuries: a systematic review with meta-analysis. Br J Sports Med 2012; 46(7): 515–23.