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14. ABSTRACT

This project was designed to assess improvements to injury mitigating and performance characteristics as tested through laboratory and field measures. Based on several meetings with MARSOC Command, Medical, and Human Performance personnel, prioritized objectives, and consideration for previously accomplished research within the Special Operations Forces community, the scope of this project was developed. The overall objective of this project was to measure the effectiveness of human performance programming implemented by MARSOC to refine human performance training based on identified needs of the Force. Two aims were executed: 1) To measure the effectiveness of the MARSOC human performance program to improve injury mitigating characteristics based on previously completed trial and available data and 2) To perform longitudinal biomechanical, musculoskeletal, and physiological testing at Assessment and Selection, Pre-Individual Training Course (ITC), and Post-ITC.

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Scientific and Technical Objectives (200 Words)

This project was designed to assess improvements to injury mitigating and performance characteristics as tested through laboratory and field measures. Based on several meetings with MARSOC Command, Medical, and Human Performance personnel, prioritized objectives, and consideration for previously accomplished research within the Special Operations Forces community, the scope of this project was developed. The overall objective of this project was to measure the effectiveness of human performance programming implemented by MARSOC to refine human performance training based on identified needs of the Force. The project's focus and objectives were finalized in 2014 in collaboration with CAPT Scott Cota (MARSOC Force Surgeon), Col James Christmas (Preservation of the Force and Family (POTFF) Representative), and Mr. Brad Lambert (MARSOC Performance and Resiliency Director, Human Performance- Formerly PERRES). To accomplish this the following aims were completed:

To measure the effectiveness of the MARSOC human performance program to improve injury mitigating characteristics based on previously completed trial and available data

To perform longitudinal biomechanical, musculoskeletal, and physiological testing at Assessment and Selection, Pre-Individual Training Course (ITC), and Post-ITC

Approach (200 Words)

The objectives of this project were achieved with multiple trials being implemented to coincide with enrollment of Marines into MARSOC’s Basic Language Course (BLC) and other critical time points of MARSOC training. This configuration allowed for testing of a controlled trial and utilizing those who had frequent or regular exposure to MARSOC’s human performance programming. Embedded within this task were secondary objectives to evaluate differences/deficits that may exist in Combat Support Personnel/Specialists/Enablers and identify key training needs, perform an epidemiological analysis of injury data, and identify the relationship between injury and performance in MARSOC. Individual cohorts of subjects were recruited to coincide with four distinct time points: following the completion of Assessment and Selection, prior to the start of and following the completion of the ITC, and at the end of BLC during the MARSOC School pipeline. These time points were identified for their operational relevance and contact need of human performance. A clinical trial model was implemented to test Marines prior to and following completion of an eight-week intervention directed by the human performance personnel. These trials have been designed around BLC to improve study design control and focused primarily on entry level Operators.

Concise Accomplishments- Key Findings (200 Words)

Human Performance Training Program and Utilization

- Average use of human performance training for all Operators decreased over the 8-weeks of Basic Language Course (Week 1: 2.04±1.78 to Week 8: 0.93±1.39 sessions/week)
- Improvements demonstrated in peak and average anaerobic power, and trunk, shoulder, and knee strength when all Operators were analyzed together
- No differences existed when Operators were stratified based on low (<2 sessions/week- average 0.45±0.62 sessions/week) and high (>3 sessions/week- average 3.58±0.31 sessions/week) utilization of the human performance training program

Injury Epidemiology

- Incidence rate of total injuries for Operators was 37.3 injuries per 100 person-years
- Incidence rate of total injuries for Combat Support Personnel was 28.8 injuries per 100 person-years
- Incidence rate of preventable injuries for Operators was 28.1 injuries per 100 person-years
- Incidence rate of preventable injuries for Combat Support Personnel- 21.2 injuries per 100 person-years
- Mechanisms of preventable injuries
    - Operators- Running 23.3%, Lifting 30.2%
    - Combat Support Personnel- Running 50.0%, Lifting 35.7%

Human Performance and Injury

- Operators with prior injury reported in the last year performed significantly worse than the non-injured Operators in the broad jump, 5-10-5 shuttle, and 300-yard shuttle
- Operators in the top 10% of scores for broad jump, deadlift, 5-10-5 shuttle, and 300-yard shuttle did not demonstrate difference in proportion sustaining injury compared to all other Operators
- Operators who do not participate in MARSOC human performance training are 0.8-2.1x more likely to have sustained a musculoskeletal injury

Comparisons between CSO and Enablers

- CSO demonstrated significantly greater fat free mass index, anaerobic power, anaerobic capacity, maximal oxygen consumption, and knee and torso strength compared to Enablers
- Dietary intake was consistent between groups, but fueling concerns were identified for all personnel in the subgroup

Expanded Accomplishments (No Word Limit)

A total of 680 participants were enrolled in this project for a total of 1019 participant encounters. Table 1 provides a breakdown of participant demographics for enrolled participants and encounters.

Cohort	N	Age (years)	Height (m)	Mass (kg)
Selectees (Post A&S)	224	24.60 ± 2.37	1.79 ± 0.06	82.69 ± 6.98
MRTC (Students/Operators)				
Pre-ITC	133	25.34 ± 2.63	1.79 ± 0.06	83.99 ± 7.96
Post-ITC	116	25.76 ± 2.51	1.79 ± 0.06	85.23 ± 9.10
Post-BLC	127	25.75 ± 2.24	1.79 ± 0.07	85.17 ± 8.77
Operators (Battalions)	58	30.37 ± 4.04	1.79 ± 0.05	87.71 ± 9.96
Operators (Cadre/HQ)	40	32.34 ± 3.85	1.78 ± 0.06	85.29 ± 7.88
Support (Deployable)	54	27.40 ± 5.46	1.78 ± 0.08	82.50 ± 11.10
Support (Other)	19	31.13 ± 8.76	1.80 ± 0.10	89.48 ± 17.23
Intensive Integrated Rehab	9	36.30 ± 6.78	1.78 ± 0.09	86.56 ± 17.34
Other	11	25.85 ± 2.15	1.82 ± 0.09	88.46 ± 15.36
Prelab Survey	85	28.56 ± 4.51	N/A	N/A

Individual accomplishments are outlined with specific key findings for each analysis and direct application bolded and italicized.

Patterns and Associations of Shoulder Motion, Strength, and Function in MARSOC Personnel Without History of Shoulder Injury (Full Manuscript Appendix 1)

Military personnel are at an increased risk of shoulder injuries due to training and deployment demands, however, there is a lack of information on the tactical athlete's upper extremity profile. Therefore, the purpose of this study was to examine shoulder musculoskeletal characteristics, including range of motion (ROM), strength, and function, and the relationships between these measures in Marine Corps Forces Special Operations Command (MARSOC) personnel without history of shoulder injury. Participants included 195 full-duty male MARSOC personnel (age: 25.38 ± 2.85 years; height: 1.79 ± 0.06 m, mass: 82.79 ± 7.88 kg) without history of shoulder injury. Measurements of ROM, strength, and function were obtained bilaterally. Shoulder internal rotation (IR) and external rotation (ER) ROM were summed to calculate total arc of motion (ARC). Shoulder IR and ER strength were assessed using an isokinetic dynamometer. Function was evaluated with an explosive push-up. MARSOC personnel present with significantly increased ER ROM, and decreased IR ROM and ARC in their dominant shoulder. They demonstrated greater IR strength and peak force during the explosive push-up on the dominant side but no bilateral differences in average or peak rate were found. Correlation analyses suggest a weak inverse relationship between strength and ARC ($r = -0.15$ to -0.24). A positive relationship between strength and function were identified except for dominant IR strength and push-up variables. Those with the greatest ARC demonstrated significantly weaker IR and ER strength compared to those with less motion. MARSOC personnel demonstrate shoulder ROM and strength symmetry patterns similar to overhead athletes. Increased dominant shoulder strength does appear to translate to a bilateral functional performance, but overall performance may be limited by the weaker nondominant upper extremity. As ARC increases, IR and ER rotation strength decrease. Repetitive, increased loading of the dominant shoulder during functional movements and training may increase risk of chronic, overuse-type injuries, common to the military. ***Unilateral exercises and movement analysis should be incorporated to encourage proper development of bilateral shoulder strength***, which may be particularly important in those with high ranges of ARC.

Physical, Physiological, and Dietary Comparisons between Marine Corps Forces Special Operations Command Critical Skills Operators and Enablers (Full Manuscript Appendix 2)

Tactical demands of a Marine Corps Forces Special Operations Command (MARSOC) Critical Skills Operator (CSO) require high levels of physical performance. During combat deployments, teams of CSOs are supplemented with Enablers who specialize in mission-specific tasks. MARSOC CSOs and Enablers serve alongside each other in extreme combat environments, often enduring the same physical demands, but the selection process for each group is very different. The purpose of this observational study was to quantify the physical, physiological, and dietary differences of MARSOC CSOs and Enablers, as this may have a direct impact on tactical performance and provide important information to shape future research. Fat free mass (FFM), fat mass (FM), fat mass index (FMI), fat free mass index (FFMI), anaerobic power (AP), anaerobic capacity (AC), aerobic capacity (VO2max), knee flexion (KF), knee extension (KE), trunk extension (TE) and trunk flexion (TF) isokinetic strength were collected. Dietary intake was collected using automated self-administered 24-hr dietary recalls (ASA24®) for a subgroup of subjects. Testing on 164 male CSOs (Age: 27.5 ± 3.8 years, Height: 178.7 ± 6.5 cm, Mass: 85.7 ± 9.1 kg, and 7.6 ± 2.9 years of military service) and 51 male Enablers (Age: 27.8 ± 5.4 years, Height: 178.4 ± 8.5 cm, Mass: 83.8 ± 11.8 kg, and 7.9 ± 5.4 years of military service) showed there were no significant differences for age, height, mass, or years of military service. ($p>0.05$). CSOs demonstrated greater physiological performance in AP (W/kg) ($p=0.020$), AC (W/kg) ($p=0.001$), and VO2max (ml/kg/min) ($p=0.018$). There were no significant differences in FM and FFM ($p > 0.05$), however CSOs demonstrated significantly higher FFMI ($p=0.011$). CSOs also demonstrated greater KF (%BW) ($p=0.001$), KE (%BW) ($p=0.001$), TE (%BW) ($p=0.010$), and TF (%BW) ($p=0.016$). No differences in energy or macronutrient intake were observed in the subgroup. ***MARSOC CSOs demonstrated significantly greater FFMI, AP, AC, VO2max, KF, KE, TE, and TF compared to Enablers. Dietary intake was consistent between groups, but fueling concerns were identified for all personnel in the subgroup***. These findings suggest the need for future studies to examine ***what physiological and strength thresholds are necessary to operate effectively as a member of a MSOT*** and determine the relationship between specific performance deficits and risk of injury. In addition, the integration of nutrition strategies that augment and optimize the performance of both CSOs and enablers may be beneficial.

Altered Physical Performance Following Advanced Special Operations Tactical Training (Full Manuscript Appendix 3)

The purpose of this study was to determine how the unique challenges of specific military tactical training phases influence overall physical performance characteristics. Broad jump, 5-10-5, 300 yard shuttle, percent body fat (%BF), anaerobic power (AP) and capacity (AC), maximal oxygen uptake (VO_2max), isokinetic knee extension/flexion strength, shoulder internal/external rotation strength, trunk extension/flexion strength, were collected on 73 United States Marine Corps Forces Special Operations Command (MARSOC) students (Age: 27.4 ± 3.8 years, Height: 178.7 ± 6.6 cm, Mass: 85.8 ± 9.4 kg) at the beginning of (P1), in between (P2), and at the completion of two distinct tactical training phases (P3). Linear mixed models were used to analyze within-subject performance changes over the three time points and post-hoc Bonferroni pairwise comparisons analyzed performance changes between each testing time point. There were significant changes in broad jump ($p<0.0001$), 5-10-5 agility time ($p<0.001$), %BF ($p=0.011$), AP ($p<0.0001$), VO_{2max} ($p=0.001$), and both right and left shoulder internal rotation strength ($p=0.004$ and $p=0.015$ respectively) between P1 and P2. There were also significant changes in 300-yd shuttle run time ($p=0.001$), AP ($p<0.0001$), AC ($p<0.0001$), left knee extension strength ($p=0.006$), trunk flexion strength ($p<0.0001$), and left shoulder external rotation strength (0.027) between P2 and P3. ***Identifying the affect that specific tactical training phases may have on physical performance will allow for the development of effective phase specific evidence-based human performance programs***, reducing performance deficits and thereby reducing the risk of injury.

Influence of Limb Dominance and Shoulder Injury on Strength and Explosive Force in US Marines (Full Manuscript Appendix 4)

The specialized roles of many military personnel require specific skills and high physical demands, placing unique stresses on the shoulders and increasing risk of injury. As normal dominant/nondominant shoulder asymmetries have been established in competitive uninjured athletes, bilateral strength comparison to monitor patients' progress or readiness to return to duty must be understood in context of daily physical demands. Presentation of functional deficits following injury may differ between dominant and nondominant side pathology. These differences may require individualized rehabilitation strategies to address deficits specific to the injured side. Therefore, this study aims to assess bilateral differences in strength and explosive force in Marines with a history of dominant or nondominant shoulder pathology. A total of 220 full-duty male Marines (age: 25.83 ± 3.18 years; height: 1.79 ± 0.06 m, mass: 83.53 ± 8.29 kg). Bilateral shoulder internal (IR) and external (ER) rotation strength were assessed at 60° per second using an isokinetic dynamometer in a modified neutral position while bilateral peak forces during an explosive push-up (PUSH) were collected using a 3-D motion system with two force plates. Dominant compared to nondominant side data were examined within each group (CON: no history of shoulder injury, DOM: dominant shoulder injury within the last year, NOND: nondominant shoulder injury within the last year) independently. Paired-samples t-tests or Wilcoxon Signed Ranks Tests were used to analyze between-limb differences within each group ($P < 0.05$). CON ($n = 186$) demonstrated asymmetrical shoulder IR strength ($P <0.001$), but not ER strength and PUSH. NOND ($n = 18$) demonstrated significantly less IR ($P = 0.001$) and ER ($P = 0.006$) strength and PUSH ($P = 0.009$) on the injured side, while DOM ($n = 16$) demonstrated no bilateral differences in strength or PUSH. ***Military personnel may develop specific asymmetric strength patterns due to increased demand of the dominant shoulder for specific unilateral or dissociated tasks***. NOND performed differently than DOM, presenting with both strength and PUSH asymmetries. ***Common clinical practice and previous literature often compares injured and uninjured limbs, but further distinction of dominant or nondominant side of injury may provide more accurate information needed to develop targeted treatment strategies***. Recognizing unique occupational demands and how patients may present differently with dominant versus nondominant side shoulder injuries are important considerations for ensuring accurate assessment and effective individualized rehabilitation.

Human Performance Training Program Utilization and Training Outcomes in United States Marine Corps Forces Special Operations Command Operators (Full Manuscript Appendix 5)

At the onset of project development in which the aims were established, the main focus was on testing the effectiveness of the human performance program. Prior research within the SOF community by our team was used in part to develop the program in place for 2014. To meet physical occupational demands, Marine Corps Forces Special Operations Command (MARSOC) has implemented a human performance training (HPT) program. The utilization and performance adaptations of this voluntary HPT program are not known. Five clinical trials were implemented with Specialists and Entry Level Operators (Table 2).

Table 2. Clinical Trial Status

Trial #	Group	Pretest	Posttest	% Complete
1	Combat Support	18	1	5.6
2	15-1	17	17	100
3	15-2	32	24	75
4	16-1	50	40	80
5	MDIOC	13	10	76.9

Trial #1 was completed with Marine Corps Special Operations Command (MARSOC) Specialists. Eighteen total Marines were recruited and enrolled in the clinical trial to evaluate changes in physical performance following eight weeks of human performance training. Each Marine completed pre-course physiological, musculoskeletal and biomechanical assessments. At baseline testing, all Marines were informed and agreed to participate in eight weeks of human performance training followed by a posttest re-evaluation. Two Marines completed the eight-week training program but only one completed post testing as the other deployed prior to being able to complete post testing. Another Marine completed post testing but was assigned to SERE during the PERRES training period, so did not complete the PERRES training program. The other 15 Marines were unavailable for post testing for various reasons including deployment, reassignment, going on leave, completing SERE, and loss of interest. In summary, 18 Marines completed pretesting, two completed post testing, with only one of those completing the eight-week PERRES program. Trials #2-4 were implemented with Marines (Entry Level Operators) enrolled in Basic Language Course. This recruitment strategy was adopted to improve overall study design and compliance of subject participation. Multiple classes were recruited to reach the desired sample size. Per USSOCOM guidance, all Operators are to participate in their Component's human performance programming. With consideration of this directive, separate control groups were not included in the design but identified from human performance participation (compliance to intervention). All Marines performed baseline testing consisting of biomechanical, musculoskeletal, physiological, and performance testing. A clinician-guided self-report injury history and nutrition survey were also administered. The human performance program (formerly Performance and Resiliency) was developed by MARSOC's strength and conditioning specialists to optimize Marines' physical resilience and performance. The program was designed "to deliver a high-level training that incorporates injury prevention, strength, speed, and energy system development as it relates to tactically relevant job demands." Post-intervention testing was completed after eight weeks of human performance participation. Trial

#5 was completed with Marine Corps Special Operations Command (MARSOC) Specialists enrolled in Multi-Discipline Intelligence Operators Course (MDIOC). Thirteen support personnel were tested prior to the start of MDIOC. Three of the participants were dropped from MDIOC during the course. The remaining 10 participants were retested at the end of the course. Pre and post testing of this course was selected as consistent 8-weeks of human performance training was anticipated, however, at retest, most participants reported inconsistent HP training due to course demands. Most reported regular use for first month of course (3x/week), but then missed several weeks due to course requirements. Individuals attended this course to work towards Special Operations Capabilities Specialist (SOCS- 8071) MOS. Two of the participants were currently not assigned to MARSOC and returned to their position with USMC following the course. Final analysis of entry-level operators (n=45, Age:25.6±2.5 years, MARSOC Experience:0.76±0.07 years) were tested at the beginning (Pre) and following 8-weeks (Post) of MARSOC's Basic Language Course. Use of the HPT program was recorded by MARSOC human performance personnel. Pre and post trunk, shoulder and knee strength, anaerobic power, and aerobic capacity were measured. Data were analyzed for all operators as well as comparing low (LU, <2) and high (HU, >3 sessions/week) utilizers. ***Use of the HPT program for all operators decreased over the 8-weeks (2.04±1.78 to 0.93±1.39 sessions/week, p<0.05). When data from all operators were analyzed, increases in trunk flexion (p<0.001), right shoulder external rotation (p=0.020), left knee extension (p=0.044), peak (p<0.001) and mean anaerobic power (p<0.001) were observed.*** Twenty-four operators were classified as LU (0.45±0.62) and 15 as HU (3.58±0.31 sessions/week). There were no significant differences in training outcomes between the LU and HU groups. ***Utilization of the HPT program varied between and within individuals***. Additional improvements in performance outcomes may require longer or more consistent use of the program. Additional research is required to understand the barriers to program utilization to improve its effectiveness.

Injuries in Operators and Support Personnel in Marine Special Operations (Full Manuscript Appendix 6)

Special Operations Forces Operators (OPs) sustain greater rates of musculoskeletal injuries than conventional forces. In addition to OPs, Marine Corps Forces Special Operations Command (MARSOC) also utilize Combat Support Personnel (CSP), which are critical for mission operations and readiness. Describe injury epidemiology in MARSOC personnel and compare injury patterns between OPs and CSP. A total of 152 MARSOC personnel (98 OPs, 54 CSP) completed an injury history questionnaire to describe musculoskeletal injuries that occurred in the previous 12 months. Injury proportions were calculated and Fisher's exact tests were used to compare proportions. A total of 71 injuries within the previous 12 months were recorded, 39 of which were classified as preventable and reported by 25 personnel (12 OPs, 13 CSP). There were no statistically significant differences in the proportion of subjects reporting preventable injuries between OPs and CSP. ***Both OPs and CSP sustained the majority of preventable injuries while performing running and lifting activities (23.3% and 30.2% for OPs and 50.0% and 35.7% for CSP, respectively). OPs and CSPs sustained 34.62% and 59.1% of preventable injuries during physical training related activities, respectively.*** Also, the lumbopelvic and knee regions were the most commonly reported locations of preventable injuries for OPs (23.1% and 15.4%) and CSP (22.7% and 31.82%). OPs and CSP seem to sustain similar injury patterns with similar mechanisms, suggesting CSP should also be included in injury prevention initiatives to optimize force readiness. Additionally, the majority of injuries sustained were preventable and sustained during physical training, suggesting significant potential benefit from injury prevention programs to mitigate preventable injuries and optimize force readiness.

Lifestyle Risk Factors in US Marines: Is There a Relationship to Injury? (Full Manuscript Appendix 7)

Musculoskeletal injuries are a significant contributor to overall lost duty days, increased medical costs, and reduced readiness in the military. Lifestyle risk factors such as too low or excessive body fat, alcohol consumption, and tobacco use are known to contribute to overall health and wellness. Previous studies have indicated these lifestyle risk factors may be related to injury, and tobacco use, in particular, is common among service members. Although previous studies suggest that such lifestyle habits may contribute to greater risk of injury, there has yet to be a specific study that examines these issues in the Marines. The purpose of this study is to examine the relationship between lifestyle risk factors and musculoskeletal injury in Marines. Self-report survey data was collected through a questionnaire completed by 423 Marines (26.5±4.5 years, 179.1±6.4 cm, 84.1±8.9 kg, BMI=27±2.2 kg/m^2, body fat percentage=14.9±5.4%). Data collection occurred in a performance research laboratory environment during a functional testing session. Information collected included demographics, injury history, and lifestyle habits. Injuries were only included if they occurred within the past year; both acute and chronic injuries were included. Body fat percentage was measured using air displacement plethysmography. A chi-square analysis was used to examine relationships between dichotomos variables. A logistic regression was performed to ascertain the effects of BMI, body fat percentage, alcohol consumption, and history or current use of tobacco on the likelihood that participants will sustain an injury. Of the 423 Marines in this study, 31.2% reported having an injury in the past 12 months. History or current usage of cigarettes, cigars, and smokeless tobacco were reported respectively by 33% (139/423), 8% (32/423), and 41% (173/423) of Marines surveyed. History or current use of tobacco was associated with injury occurrence within the past year (χ^2=6.89, p=0.009). Current alcohol usage was reported by 77% (325/405) of Marines, averaging 3.5 servings per week. No association was detected between alcohol consumption and injury within the past year (r=-0.07, p=0.085). The logistic regression model was statistically significant (χ^2 = 7.34, p <0.007). ***This model correctly classified 67.5% of cases and identified history or current usage of tobacco as the only significant factor.*** Although Marines are required to be physically and mentally fit due to the intense demands of the job, they are still affected by poor health related habits that may influence their risk for musculoskeletal injury. Lifestyle risk factors such as carrying excess body fat and tobacco use are related to poor overall health, and may be related to musculoskeletal injury. This study has indicated a weak relationship between BMI, body fat percentage, and tobacco and musculoskeletal injury in Marines. When clinicians develop prevention or rehabilitation programs, it is important to consider these lifestyle risk factors and habits in patient education, prognosis, recovery. These findings may also provide supporting evidence to military leadership to further support services that assist service members in improving these habits.

Comparison of Physical and Physiological Characteristics based on Injury History

US Marines perform extremely demanding training and tactical tasks that come with inherent musculoskeletal injury risk. These injuries limit the physical and tactical readiness required of Marines. Recovery from musculoskeletal injury is not only critical to optimizing resiliency and well-being, but tactical performance and recurrent injury mitigation. The purpose of this study was to compare physical and physiological characteristics in Marines based on a retrospective analysis of injury history. A total of 71 Marines completed testing for isokinetic strength, flexibility, body composition, aerobic capacity/lactate threshold, and anaerobic power/capacity. Marines were stratified based on self-reported injury history for the past 12 months (Previously Injured: (N = 13), Age: 27.9 ± 5.8 years, Height: 179.1 ± 6.6 cm, Mass: 85.7 ± 7.1 kg; Non-Injured: (N = 58), Age: 28.9 ± 7.0 years, Height: 179.1 ± 6.1 cm, Mass: 84.7 ± 9.9 kg). Mann-Whitney U Tests were used to analyze the data between cohorts of Marines ($p < 0.05$). A prior musculoskeletal injury was reported in 18.3% of Marines and regionally reported at 53.9% for the lower extremity, 38.5% for the spine, and 7.6% for the upper extremity. No significant differences existed between cohorts for demographics ($p = 0.338 – 0.491$) or years of experience ($p = 0.446$). The previously injured Marines demonstrated significantly weaker torso extension (Previously Injured: 323.8 ± 65.3 %BW, Non-Injured: 398.8 ± 90.0 %BW, $p = 0.003$) and knee flexion (Previously Injured: 114.1± 22.2 %BW, Non-Injured: 128.9 ± 29.6 %BW, $p = 0.035$). No significant differences were demonstrated for other strength comparisons or flexibility, body composition, and aerobic/anaerobic performance comparisons ($p = 0.058 – 0.489$). Although limited differences in physical and physiological characteristics exist, ***restoration of trunk extension and knee flexion strength may be critical to prevent the recurrence of musculoskeletal injury. This is essential given the frequency of injury to the spine and lower extremity and the importance of these muscles to transfer load through the kinetic chain during multi-joint movements***. Future research should consider a prospective analysis of Marines to determine injury risk associated with physical and physiological characteristics.

Knee Extension Strength Asymmetry does not Affect Peak Power or Fatigue during the Wingate Test

Peak and mean power during the Wingate test is associated with knee extensor strength, however it is unknown if knee extensor asymmetry affects this relationship. We hypothesized that increased muscle asymmetry would be associated with decreased peak and mean power during the Wingate test in healthy subjects. A total of 206 highly active male subjects (27 ±4 yrs, 84 ±9 kg) completed individual limb isokinetic strength testing on a dynamometer ($60°\cdot sec^{-1}$), as well as a 30 second Wingate anaerobic test in a seated position. Strength testing included maximal knee extension strength ($Nm\cdot kg^{-1}$). Knee extension asymmetry ratio between legs (A_{ext}) was calculated as $A_{ext} = E_{min}/E_{max}$, where E_{max} = strongest leg, E_{min} = weakest leg. Subjects were later classified as High Symmetry (HS, $A_{ext} \geq 0.95$, n=76), Moderate Symmetry (MS, $0.90 \leq A_{ext} < 0.95$, n=60), Moderate Asymmetry (MA, $0.85 \leq A_{ext} < 0.90$, n=35) or High Asymmetry (HA, $A_{ext} < 0.85$, n=35). Wingate data ($W\cdot kg^{-1}$) were analyzed for peak power (P_{peak}), mean power (P_{mean}), as well as power output at 5 second intervals. There were significant differences in E_{min} (HS > MA, p=0.012; HS > HA, p<0.001; MS > HA, p=0.044) but not E_{max} between groups. No significant differences in P_{peak} (12.89 ±0.68, 12.74 ±0.63, 12.71 ±0.52, 12.87 ±0.79 $W\cdot kg^{-1}$), P_{mean} (9.26 ±0.81, 9.05 ±0.82, 9.15 ±0.78, 9.32 ±1.08 $W\cdot kg^{-1}$) or any other power variables were found between the HS, MS, MA and HA groups respectively (all p>0.055). When all subjects were combined, knee extensor asymmetry (A_{ext}) was not associated with any power variables (all p>0.133). P_{peak} and P_{mean} respectively were positively associated with E_{max} (r=0.414, p<0.001; r=0.464, p<0.001) and E_{min} (r=0.397, p<0.001; r=0.420, p<0.001). Although all relationships were significant, the associations between strength variables (E_{min} and E_{max} respectively) and power decreased from 5 seconds (r=0.490, p<0.001; r=0.490, p<0.001) to 30 seconds (r=0.265, p<0.001; r=0.331, p<0.001). ***Greater knee extensor strength imbalance between legs is not associated with decreased power*** throughout a 30 second Wingate test. These data suggest that for bilateral tasks in which the legs do not move independently, such as cycling, ***training focused only on improving strength symmetry between legs may not improve peak power production***.

Previous History of Musculoskeletal Injury is Associated with Lower Physical Performance in US Marines

Musculoskeletal injury is an unfortunate consequence of sports and physical training. The majority of preventable musculoskeletal injuries sustained within United States military forces are due to physical training and recreational sport. Maintaining high levels of performance is dependent upon the service member's ability to adequately recover the previous injury. We currently do not know if there are performance deficits associated with previous musculoskeletal injury in this population. Therefore, the purpose of this study was to determine if current physical performance metrics are related to a history of musculoskeletal injury in a group of United States Marines. Medical and physical performance data were queried from a group of United States Marines using their internal physical performance tracking database and medical encounter data (ICD-9) exported from the Armed Forces Health Longitudinal Technology Application. This query resulted in a total of 295 subjects (155 controls, 140 Injured (84 in the previous year); age 31.2±3.5years, ranking ranging from E4-E8 and O3-O5) with complete medical and performance data. The researchers were provided with de-identified data of medical encounters and current performance testing scores. Performance scores included maximum deadlift (DL), broad jump distance (BJ), right and left 5-10-5 agility time (AG), and two 300yd shuttle times (SH). The right and left AG scores were averaged and the two SH times were used to calculate an average (SH) and a difference score (SHdiff). Each subject was classified as having had a previous musculoskeletal injury since enlistment, musculoskeletal injury within the previous calendar year, or control (no musculoskeletal diagnosis since enlistment). Musculoskeletal injury was defined as having sought out treatment that resulted in a musculoskeletal ICD-9 diagnosis code. Depending on normality of the data, one-way ANOVA or Kruskal-Wallis tests were used to identify any association between injury history and performance scores. Independent t-tests or Mann-Whitney-U tests were used for pairwise comparisons with an alpha level of 0.05 to determine if a significant difference in performance metrics existed between those with and without a musculoskeletal injury in the previous year and since enlistment. Effect sizes (ES) were calculated for all parametric comparisons. Shapiro-Wilk normality tests revealed DL, SH, and SHdiff were not normally distributed and therefore non-parametric tests were used for these analyses. One-way ANOVA analyses revealed a significant association between injury history and AG performance (F=3.582, p=0.029) but not with BJ performance. Kruskal-Wallis tests demonstrated a significant association between injury history and SHdiff (p=0.017) but not SH (p=0.062) or DL (p=0.705). Pairwise analyses showed that Marines who had a musculoskeletal injury since enlistment and within the previous year demonstrated significantly worse AG (ES=0.31, p=0.034; ES=0.33, p=0.015, respectively), SH (p=0.029; p=0.019, respectively), and SHdiff (p=0.005; p=0.028, respectively) performance compared to the controls. ***Marines with a history of musculoskeletal injury, both within the previous one year and since enlistment, show significantly lower physical performance measures***. Although this is a retrospective design and it is not possible to know if these deficits existed prior to the injury, ***these findings may suggest that Marines who sustain a musculoskeletal injury are not adequately returning to pre-injury performance levels***. Due to the rigorous tactical training schedules individuals may not have sufficient time to recover and/or address specific performance deficit. Thus, traditional strength and conditioning training may not be adequate to restore these performance deficits following injury. Future studies need to address the effectiveness and implementation of interdisciplinary care for the treatment and prevention of musculoskeletal injuries while maintaining and improving performance.

Dynamic Motor Control Deficits in Active-Duty Marines with a History of Concussion

Concussions are a common injury across all branches of the military. Military personnel who have sustained a concussion demonstrate a greater risk for lower extremity musculoskeletal injury following return to duty. The underlying mechanism for this relationship is unclear; however, residual post-concussion deficits in dynamic motor control may increase susceptibility to lower extremity musculoskeletal injuries. Therefore, the purpose of this study was to compare dynamic motor control in active-duty Marines with and without a history of concussion. Sixteen active-duty male Marines with a history of self-reported concussion (age: 24.3 ± 2.8 years; height: 1.8 ± 0.1 m, mass: 84.7 ± 7.3 kg, time since last concussion: 2.0 ± 1.2 years) were age and BMI matched to sixteen active-duty male Marines (age: 24.6 ± 2.5 years; height: 1.8 ± 0.1 m, mass: 81.8 ± 7.8 kg) with no history of concussion. All participants reported no history of musculoskeletal injury within six months of the time of testing. Dynamic motor control was assessed bilaterally using a forward jump single-leg landing task. The forward jump was initiated from two feet at a distance of 40% of the participants' height from the force plate. Participants were asked to jump over a 30 cm hurdle and land on a force plate with a single-leg and once recovered, maintain this position for 5s. Ground reaction forces during the first 3s following initial contact were used to calculate stability indices in the medial-lateral (MLSI), anterior-posterior (APSI), and vertical (VSI) directions. All stability indices were calculated based on the mean square deviations about a zero point. Dynamic Postural Stability Index (DPSI) was calculated as a composite measure of the MLSI, APSI, and VSI. Data from the left and right limbs were pooled for analysis. Group comparisons for the MLSI, APSI, VSI, and DPSI were completed with dependent samples t-tests ($p<0.05$) and corresponding Cohen's *d* effect sizes (ES). Marines with a history of concussion demonstrated poorer dynamic motor control in the MLSI (Concussion: 0.038 ± 0.007; Control: 0.031 ± 0.004, p=0.004, ES=1.32), APSI (Concussion: 0.145 ± 0.007; Control: 0.140 ± 0.006, p=0.007, ES=0.75), VSI (Concussion: 0.356 ± 0.029; Control: 0.326 ± 0.040, p=0.046, ES=0.86), and DPSI (Concussion: 0.387 ± 0.028; Control: 0.357 ± 0.038, p=0.035, ES=0.91). ***Marines with a history of concussion may have residual sensorimotor impairments despite displaying no residual symptoms from their previous concussion. Residual sensorimotor impairments; such as poorer dynamic motor control, may present a modifiable connection to the greater risk for lower extremity musculoskeletal injuries following concussion in members of the armed services***. Furthermore, examining dynamic motor control impairments in conjunction with additional factors such as cognition and emotion regulation may lead to the ***development of a multidisciplinary rehabilitation strategy to mitigate post-concussion sequalae***.

Strength and Biomechanical Contributions to Vertical Ground Reaction Forces in a Single Limb Landing Task

Reducing dynamic joint loading is a key strategy included in injury prevention landing mechanics programs. Previous research has noted the importance of increased knee flexion to reduce vertical ground reaction forces (vGRF), and the relationship between strength asymmetry and asymmetrical landing mechanics following injury. The purpose of this study was to determine if and how landing kinematics at the hip, knee, and ankle, as well as quadriceps strength contribute to vGRF in a single limb landing task. Thirty-four physically active males (Age: 27.6 ± 4.6yrs; Height: 177.74 ± 7.15cm; Mass: 84.31 ± 11.83kgs) completed a single limb drop landing off a 45.7 cm box onto a force plate. A 3D motion system was used to collect dominant (DOM) and non-dominant (NON) hip flexion at initial contact, peak knee flexion (PKF), knee flexion at initial contact (KFIC), peak ankle flexion, ankle flexion at initial contact and, peak vGRF. DOM and NON quadriceps strength (IKQS) was collected using an isokinetic dynamometer at 60°/s. Simple linear regression models were run for each limb to detect independent contributions to vGRF. Backward stepwise multiple linear regression was used to determine the best model to predict vGRF. KFIC independently accounted for 11.8% (p= 0.047) of the variance in DOM vGRF. No DOM limb multiple linear regression model was significant. KFIC and PKF independently accounted for 15.7% (p=0.021) and 16.5% (p=0.017) of the variance in NON vGRF, respectively. KFIC and IKQS as a multiple linear regression model accounted for 18.9% (p=0.043) of variance in NON vGRF. KFIC, on DOM and NON limbs, is the best sagittal plane kinematic predictor of vGRF, in a single limb drop landing task in physically active males. Despite IKQS not being an independent significant predictor on either limb, it improved KFIC prediction of vGRF on the NON limb. This study highlights how ***active males use sagittal plane knee motion and quadriceps strength to influence vGRF in a single leg landing task***, as research has shown women are more likely to use hip and knee kinematic strategies. ***Active individuals with weak quadriceps and a stiffened knee at initial contact are likely at risk for injuries associated with increased impacts during single limb landings***.

Heart Rate and Variability of Marine Corps Forces Special Operations during Close Quarter Battle Training

Enemy engagement at close proximity and making accurate decisions during close quarter battle (CQB) is a critical skill set of Marine Corps Forces Special Operations Command (MARSOC) Operators. Monitoring physiological demand and autonomic response during the tactical skills training would identify the responsive stress level to these encounters and provide the first step towards understanding the relationship between the baseline physiological stress and tactical skills and tactical proficiency (shooting accuracy and decision making). The purpose of this study was to evaluate Marines’ stress levels during CQB exercises by monitoring heart rate (HR) and heart rate variability (HRV) measures. Nine male Marines (age = 25.7 ± 2.2 years, mass = 87.1 ± 5.0 kg, height = 182.0 ± 4.7 cm) participated in CQB training during MARSOC Individual Training Course. A single channel electrocardiogram was worn during CQB activities to collect HR and HRV. Five minute resting HR/HRV measures (REST) were recorded with the subject supine. HR/HRV measures were also recorded during a waiting phase (WAIT) immediately prior to the start of the activity as well as during the CQB. Mean HR and root mean square of the mean squared differences of successive RR intervals (RMSSD) were used to assess physical demand and autonomic response as stress indicators, respectively. Paired samples t-tests were used to compare HR and RMSSD between phases. There was a significant increase in HR from REST to WAIT phase (54.5 bpm, 82.8 bpm, $p < 0.001$) and WAIT to CQB phase (82.8 bpm, 102.1 bpm, $p = 0.001$). Similarly, there was a significant decrease in RMSSD from REST to WAIT phase (136.6 ms, 34.0 ms, $p = 0.005$) and WAIT to CQB phase (34.0 ms, 15.9 ms, $p = 0.007$). ***The increased HR and decreased RMSSD found in this study are physiological indications of increased physiological demands and stress levels***. Since the current investigation is one of the first studies to quantify the HR/HRV during CQB training, future studies should examine their baseline physiological characteristics and tactical proficiency score in relation to their HR/HRV data. Additionally, future research could track their HR/HRV data and determine if there is a certain improvement that occurs with experience and training.

Decreased Trunk Strength and Altered Balance Performance in Marines with Chronic Low Back Pain

Chronic low back pain (LBP) is a common injury of many military occupations which often require high physical demands and heavy load carriage. Typically, individuals with LBP demonstrate a range of physical compromises including reduced trunk and lower extremity (LE) strength and balance. Despite injury, military personnel often maintain high operational levels masking potential deficits. Even minor alterations in capabilities could have significant impact on performance, safety, and injury risk in highly demanding environments. Therefore, this study aims to identify deficits in strength and dynamic balance in fully operational Marines with chronic LBP compared to healthy-matched controls. A total of 60 total Marines: 20 full-duty male Marines with chronic, current LBP (cLBP; age: 30.60 ± 4.38 years; height: 1.77 ± 0.06 m, mass: 86.80 ± 7.97 kg); 40 matched healthy Marines with no history of LBP and no LE injury within 1 year (CON; age: 28.71 ± 4.37 years; height: 1.79 ± 0.06 m, mass: 84.85 ± 7.75 kg). Participants completed evaluations of isokinetic knee and torso flexion and extension strength (KF, KE, TF, TE) at 60°/s and dynamic postural stability during a forward jump single leg landing task. Variability in ground reaction forces (1200 Hz) in the anterior-posterior (APSI), medial-lateral (MLSI), and vertical (VSI) directions, as well as an overall dynamic postural stability index (DPSI) were calculated during the first 3s following landing on a force plate. Independent-samples t-tests or Mann-Whitney U tests were used to assess between group differences ($P < 0.05$). Effect sizes (Cohen's d) were also calculated. cLBP demonstrated significantly lower TE strength compared to CON (3.88 ± 0.65 Nm/kg vs 4.21 ± 0.67, $P = 0.03$, $d = 0.57$). On the dominant side, cLBP demonstrated lower APSI (0.12 ± 0.03 N vs 0.15 ± 0.01 N; $P < 0.001$, $d = 1.36$) and DPSI (0.035 ± 0.03 N vs 0.37 ± 0.03 N; $P = 0.04$, $d = 0.58$) compared to CON indicating improved stability. ***Despite high overall trunk strength, cLBP demonstrated a 12.2% deficit in TE strength compared to CON***. Reduced APSI and therefore overall DPSI demonstrated by cLBP compared to CON on the dominant side may be surprising as most studies have found poorer balance in individuals with LBP. However, ***on a complex task such as used in this study, decreased APSI may suggest stiffening of the trunk***. Previous studies propose altered trunk muscle activation patterns found in individuals with LBP as a possible reason for decreased anterior posterior shear force and trunk displacement during balance tasks. Addressing TE strength in cLBP military patients may be particularly important given the high physical demands and load carriage of many occupations. While further research is needed to understand if changes in strength and dynamic postural stability are predispositions to injury and/or compensations, in highly active individuals with cLBP evaluation of movement and balance during dynamic tasks may further inform treatment and recovery.

Physical and Physiological Comparison between Cohorts of Marine Corps Forces Special Operations Command Experienced and Entry Level Operators

Marine Corps Forces Special Operations Command Operators (MARSOC) must possess optimal musculoskeletal and physiological performance characteristics to sustain health and fitness, and maintain physical readiness. Upholding these characteristics can be difficult due to age, deployment cycles and the related demands of training. The purpose of this study was to examine the effects of age and service time on physical and physiological characteristics of Experienced and Entry Level MARSOC Operators. A total of 47 Experienced Operators (Age: 32.5 ± 4.1 years, Height: 1.78 ± 0.06 m, Mass: 86.8 ± 9.7 kg, 12.16 ± 3.99 years of service) and 153 Entry Level Operators (Age: 26.1 ± 2.6 years, Height: 1.79 ± 0.06 m, Mass: 85.5 ± 8.8 kg, 6.2 ± 1.76 years of service) participated. Testing included fat mass (FM), fat free mass (FFM), anaerobic power (PAnP), anaerobic capacity (MAnP), aerobic capacity (VO_2max), %VO_2max and %HRmax at the onset of blood lactate (OBLA), knee and torso isokinetic strength testing (KF, KE, TF, TE). Differences between groups were evaluated using independent samples t-tests, or Mann-Whitney U tests if required ($p < 0.05$). Entry Level Operators demonstrated greater KF (144.0 ± 21.9 %BW, 132.8 ± 26.1 %BW; p=0.007), MAnP (9.2 ± 0.8 W/kg, 8.8 ± 0.9 W/kg; p=0.007), %VO_2max at OBLA (87.6 ± 5.1, 85.6 ± 5.7), and %HRmax at OBLA (93.0 ± 2.9, 91.4 ± 3.4). Entry Level Operators demonstrated less TF (237.6 ± 40.0%BW, 249.3 ± 36.5%BW; p=0.046). No significant differences were found in KE (p=0.067), FM (p=0.396), FFM (p=0.689), TE (p=0.204), PAnP (p=0.147), or VO_2max (p=0.075). ***Entry Level Operators demonstrated greater hamstring strength, anaerobic capacity, %VO_2max and %HRmax at OBLA than Experienced Operators***. Experienced Operators may benefit from training strategies to attenuate physiological and strength performance deficits as they age. ***Further consideration is necessary to determine what characteristics may be influenced by the combined effect of training demands, age, and overall service time and the impact on career longevity***.

Training Strategies Maintain Performance Characteristics in Marines Selected for Marine Corps Special Operations Individualized Training Course

Marines must complete an intensive Assessment and Selection (A&S) course prior to becoming a United States Marine Corps Forces Special Operations Command (MARSOC) Raider. Following selection, Marines are given training recommendations designed to maintain performance characteristics deemed relevant to successfully complete a rigorous nine-month Individualized Training Course (ITC). However, the time between the two courses is highly variable and training strategies are individually implemented by the Marine. The purpose of this study was to evaluate the effectiveness of current training strategies following A&S and prior to ITC. Fat free mass (FFM), fat mass (FM), anaerobic power (AP), anaerobic capacity (AC), aerobic capacity (VO_2max), knee flexion (KF), knee extension (KE), shoulder internal rotation (SIR), shoulder external rotation (SER), trunk extension (TE) and trunk flexion (TF) isokinetic strength were collected on 38 Marines (Age: 25.7 ± 2.6 years, Height: 1.77 ± 0.05 meters, Mass: 83.2 ± 7.7 kg, Post A&S to ITC Start: 204.1 ± 68.4 days) following A&S and directly prior to ITC. No significant changes were found in Marines between A&S and the start of ITC in FFM ($p=0.596$), FM ($p=0.134$), AP ($p=0.266$), AC ($p=0.376$), VO_2max ($p=0.540$), KF ($p=0.437$), KE ($p=0.602$), SIR ($p=0.785$), SER ($p=0.369$), TE ($p=0.427$), and TF ($p=0.856$). ***Performance characteristics were similar following selection and prior to the start of ITC, suggesting the current training strategies, as implemented and adopted for the varying time gaps post A&S, were effective at maintaining performance between courses***. Although effective at sustaining performance levels, Marines still demonstrated deficits in AP (13.0 W/kg vs 12.65 W/kg respectively) compared to previous studies on MARSOC Raiders. Future training strategies may further benefit from an increased emphasis on AP in conjunction with current recommendations. Additionally, further research is needed to determine how performance characteristics are affected by variance in time between courses.

Association Between Knee Strength and Landing Biomechanics in Marine Corps Forces Special Operations Command Operators

Marine Corps Forces Special Operations Command (MARSOC) Operators are required to perform a multitude of complex tactical movements. Understanding the strategies used to attenuate shock during different dynamic tasks may provide insight into mechanisms associated with an increased risk of injury. The purpose of this study was to examine landing mechanics and the association between knee strength and specific landing strategies. Knee strength and sagittal plane knee kinematics were collected on 41 Operators (Age: 28.4 ± 6.1 years, Height: 178.8 ± 6.7 cm, Mass: 85.4 ± 7.9 kg). Knee extension strength (KES) was collected using an isokinetic dynamometer. Knee angle at initial contact (K@IC), peak knee flexion (pkKF), and peak vertical ground reaction forces (VGRF) were collected during a Forward Jump Single-Leg Landing task (FJSL) and a Double-Leg Drop Landing (DLDL) using a 3-D motion capture system. Pearson correlation coefficients examined the relationships between strength and landing mechanics. Paired samples t-tests examined asymmetries in strength and landing mechanics. Significance was set at $p \leq 0.05$. Increased K@IC and pkKF correlated to decreased VGRF during the DLDL ($r=-0.327$, $p=0.037$ and $r=-0.643$, $p<0.001$ for the right and $r=-0.375$, $p=0.016$ and $r=-0.638$, $p<0.001$ for the left), but these correlations were not significant during FJSL. KES did not correlate to any knee kinematic measures for their respective sides. Operators demonstrated asymmetrical KES ($p=0.023$) but not asymmetrical K@IC, pkKF, or VGRF during either the FJSL ($p=0.825$, $p=0.097$, $p=0.998$ respectively) or DLDL ($p=0.703$, $p=0.246$, $p=0.380$ respectively). During DLDL, minimizing VGRF involved the knee, but these strategies were not associated with KES, indicating factors other than KES play a role. During FJSL, which is a complex movement that incorporates balance, the relationship between knee kinematics and VGRF diminished, indicating that different landing strategies were required. ***Tactical movements are often complex, incorporating a combination of factors such as shock absorption and balance. Understanding how landing strategies change with increased complexity will provide insight into specific mechanism associated with injury allowing for the design of effective injury prevention training strategies***.

Association between Rate of Torque Development, Strength, Landing Biomechanics, and Dynamic Postural Stability in Physically Active Males

During exercise and sport, physically active individuals often perform movements that require dynamic postural stabilization. Postural stability has been linked to ankle and knee injuries and examining factors associated with stabilization may provide insight as to how poor stability influences joint loading. The purpose of this study was to examine mechanisms associated with postural stability during a Forward Jump Single-Leg Landing task (FJSL). Dynamic postural stability index (DPSI), a composite of the anterior-posterior, medial-lateral, and vertical ground reaction forces, kinematics, knee extension strength (KES), and knee extension rate of torque development (RTD) were collected on 23 males (Age: 23.9 ± 1.3 years, Height: 178.4 ± 7.1 cm, Mass: 84.4 ± 8.6 kg). KES and RTD were collected using an isokinetic dynamometer. DPSI, sagittal plane joint angles at initial contact (Hip@IC, Knee@IC, ANK@IC) and peak flexion angles (KneePkFlex, ANKPkFlex) were collected during a FJSL for the dominant (DOM) and non-dominant (NON) limb using a 3D motion capture system. Paired samples t-tests examined lower extremity asymmetries in DPSI, kinematics, KES, and RTD. Pearson correlation coefficients examined the relationships between KES, RTD, DPSI, and landing kinematics. Significance was set at $p \leq 0.05$. Subjects demonstrated asymmetrical DPSI ($p=0.003$) and asymmetrical ANKPkFlex ($p=0.033$) but not asymmetrical KES or RTD ($p>0.05$). Increased KneePkFlex and ANKPkFlex correlated with an improved DPSI ($r=-0.519$, $p=0.016$ and $r=-0.466$, $p=0.033$) on the DOM limb while KneePkFlex and HIP@IC correlated with an improved DPSI on the NON limb ($r=-0.472$, $p=0.031$ and $r=-0.520$, $p=0.016$). Neither KES nor RTD correlated with DSPI or any of the kinematic measures for their respective sides. ($p>0.05$). Biomechanical stabilization strategies utilized the knee but the DOM, which had better stabilization, incorporated more ANKPkFlex, likely distributing weight over the forefoot. Neither strategy related to KES or RTD. ***Incorporating movement and balance components focused on symmetrical coordination of corrective movement strategies, including ankle stability, into current training programs may be necessary for improved dynamic postural stabilization***.

Dynamic Postural Stability and Landing Mechanics During a Single-Leg Landing in Individuals with a Previous Knee Injury

Altered neuromuscular activation patterns following a musculoskeletal injury may inhibit the control of the lower extremity during dynamic movements. Physically active individuals often perform complex dynamic movements that require both shock absorption and postural stabilization. Postural stability has been linked to ankle and knee injuries and examining factors associated with stabilization may provide insight as to how musculoskeletal injuries may influence stability and joint loading during dynamic movements. The purpose of this study is to determine if physically active individuals with a self-reported knee injury occurring within the last year have decreased knee extension strength, altered landing mechanics, or altered stabilization strategies during a forward jump single-leg landing task. We hypothesized that those with a history of knee injury will have decreased knee extension strength, land with a stiffened knee strategy, and with less stability compared to controls. Knee strength and lower extremity kinematics were collected on 31 physically active males, 16 with a previous self-reported knee injury (age 26.9±3.9yrs; height 180.48±6.31cm; mass 83.69±7.68kg), and 15 control subjects without a history of lower extremity injuries (age 25.2±2.7yrs; height 179.32±5.36cm; mass 82.27±8.02kg). All subjects performed a self-reported injury history questionnaire guided by a licensed clinician. Injuries were defined as a musculoskeletal injury event that occurred within the last year from the date of the questionnaire and resulted in altering physical training for at least one day. Healthy control subjects reported no history of lower extremity injuries. Individuals reporting bilateral injuries, neurological conditions, and musculoskeletal injuries affecting other lower extremity joints were excluded from this analysis. Knee extension strength (KES) was collected using an isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY) and normalized to body mass for group comparisons. Lower extremity kinematics, peak vertical ground reaction forces (pkVGRF), and dynamic postural stability index (DPSI), a composite of the anterior-posterior, medial-lateral, and vertical ground reaction forces were collected during a Forward Jump Single-Leg Landing task (FJSL). Subjects were instructed to jump forward, clearing a hurdle approximately 31 cm in height, landing on a single limb, stabilizing rapidly and maintaining postural control following the landing. Subjects were outfitted with reflective markers and lower extremity kinematics were collected using an 8-camera 3D motion capture system (Vicon Motion Systems Ltd, Centennial, CO) and vertical ground reaction forces were collected by two force plates at 1200 Hz (Kistler Instrument Corp., Amherst, NY). Data were processed with Vicon Nexus software using a Plug-in-Gait model. Marker trajectories were filtered using a Woltering filter with a predicted mean square error at 10mm. Hip, knee and ankle flexion and adduction angles at initial contact (@IC) and peak flexion angles (pkFlex) were recorded from the kinematic analysis. Independent samples t-tests were used to examine differences in KES, kinematics, and DPSI between those who experienced a knee injury within the last year (INJ) and those with no history of lower extremity injuries (CON). Paired samples t-tests were used to evaluate lower extremity asymmetries between the injured and uninjured limbs within the INJ group using the same measures as the group comparison. Pearson correlation coefficients examined the relationships between KES, landing kinematics, pkVGRF, and DPSI. All data were analyzed using SPSS (SPSS 22 IBM Corp, Armonk, NY). Significance level was set at alpha = 0.05. There were no significant differences in KES, pkVGRF, or DSPI between groups ($p>0.05$, respectively). The INJ group had significantly lower KES in the injured limb compared to that of the uninjured limb ($p=0.006$) and these KES asymmetries were not observed in the CON group (($p=0.331$), Figure 1). There were no significant differences between the injured and uninjured limb within the INJ group for any of the kinematic measures, pkVGRF or DPSI (p>0.05, respectively). Within the INJ group increased KES significantly correlated to a decreased pkVGRF and an improved DPSI but only when landing on the uninjured limb. When landing on the injured limb, KES did not correlate to pkVGRF, DPSI or any kinematic measure (p>0.05, respectively). HipFlex@IC correlated to pkVGRF during the FJSL task for both the injured and uninjured limb while AnkleFlex@IC correlated with pkVGRF for the injured limb only. Though there were no significant differences between the INJ and CON groups, we found between limb KES asymmetries within the INJ group that were not observed in the CON group. Furthermore, ***the asymmetrical KES observed in the INJ group may influence pkVGRF and DPSI differently between limbs. Individuals reporting a knee injury within the last year may experience decreased KES for a significant period of time following the injury***. Though asymmetrical KES within the INJ group did not lead to asymmetrical pkVGRF, or DPSI it may have altered the strategies used between the different limbs to achieve similar shock absorption and stabilization. Based on the lack of correlations between KES and the biomechanical outcomes on the injured side, ***individuals may attempt to compensate for the decreased KES by relying more on the ankle during landing***. Due to the limited sample size, complexity of the task, and the differing severities of the knee injuries further research is needed to determine if specific compensation strategies are utilized for shock absorption and stabilization and examine if these strategies translate to other dynamic movements. Individuals who reported having a knee injury demonstrated KES asymmetries within one year following their injury. Further research is needed to investigate how decreased muscle function, including KES and neuromuscular function following a knee injury influence joint specific loading and dynamic joint stability during both bilateral and unilateral dynamic movements.

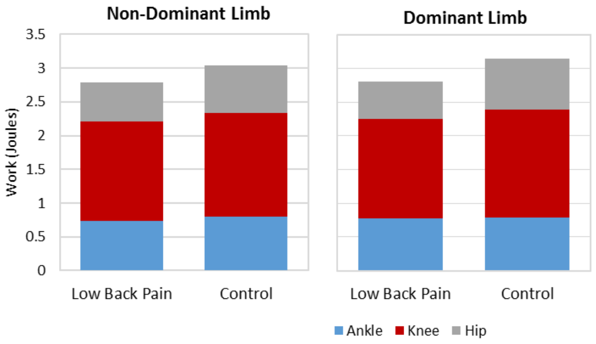
Individuals with a History of Ankle Injuries Demonstrate Altered Biomechanical Characteristics during a Stop Jump Task

Lower extremity non-contact musculoskeletal injuries are extremely prevalent in a variety of highly active populations, with acute and chronic ankle injuries being one of the more commonly experienced lower extremity injuries. Power absorption at the ankle joint is critical for effectively attenuating shock, helping to reduce impact and dynamic loading to the rest of the lower extremity joints. Therefore the objective of this study was to determine if highly active personnel with a history of ankle injuries exhibit deficits in ankle power absorption during an explosive bilateral dynamic movement. It was hypothesized that subjects reporting a history of at least one ankle injury will demonstrate impaired ankle mechanics during a stop jump task. Lower extremity kinematics and kinetics were collected on 38 physically active individuals, 20 male subjects reporting at least one ankle injury (INJ) (age 25.9 ± 2.5 yrs; height 178.1□6.7 cm; mass 82.2 ± 5.8 kg, 51.2 ± 33.3 months since injury), and 18 male control subjects without a history of lower extremity injuries (CON) (age 25.8 ± 2.5 yrs; height 178.6□4.1 cm; mass 84.4 ± 5.9 kg). All research procedures were approved by the University's Institutional Review Board and written informed consent was obtained from each subject prior to participation. All subjects performed a self-reported injury history questionnaire guided by a licensed clinician. Ankle injuries were defined as a musculoskeletal injury to the ankle that occurred and resulted in altering physical training for at least one day. Individuals reporting bilateral injuries, neurological conditions, and additional lower extremity injuries were excluded from this analysis. Subjects were outfitted with reflective markers and lower extremity biomechanics were collected during a Double-Leg Stop Jump (DLSJ). During the DLSJ subjects were instructed to jump forward, using both legs, landing on two separate force plates from 40% of their height and upon landing immediately transition into an explosive maximal effort vertical jump. Lower extremity biomechanics were collected using an 8-camera 3D motion capture system and two force plates at 200 and 1200 Hz respectively. Data were processed using a Plug-in-Gait model. Data were assessed for normality via Shapiro-Wilk tests. Between groups analyses of ankle kinematics and kinetics compared the involved (INV) and uninvolved (UNINV) limbs of the INJ to the dominant (DOM) limb of the CON using either Independent samples t-tests or Mann-Whitney U-tests. Spearman rank-order correlation coefficients examined the relationships between ankle kinematics and kinetics. All data were analyzed using SPSS (SPSS 24 IBM Corp, Armonk, NY). Significance was set at $p<0.05$. The INJ group demonstrated significantly greater peak vertical ground reaction forces (pkVGRF) on both the involved (237.08 ± 68.28 %BW; $p=0.028$) and uninvolved (242.42 ± 74.27 %BW; $p=0.050$) limbs during the landing phase of the DLSJ compared to that of CON (187.19 ± 42.26 %BW). The INJ group also demonstrated a greater external dorsiflexion moment at the ankle for both the involved (1.67 ± 0.66 Nm/kg; $p=0.031$) and uninvolved limb (1.70 ± 0.73 Nm/kg; $p=0.017$) compared to that of the CON group (1.27 ± 0.030 Nm/kg). No significant differences were found in either peak power absorption or peak power generation at the ankle between the two groups ($p>0.05$). Significant correlations between pkVGRF and peak ankle power absorption were found for both the involved ($r=-0.824$, $p=0.0001$) and uninvolved limbs ($r=-0.690$, $p=0.002$) within the CON group but these relationships were not present in the INJ group. INJ subjects adapted a landing strategy during the DLSJ that was different than that of CON, landing with significantly greater force (increased pkVGRF) and placing greater stress (increased moment) on the ankle. Though there was no significant difference in power absorption between the two groups, the fact that the CON group increased power absorption at the ankle with increased landing force (positive significant spearman rank-order correlations; $p<0.05$) while the INJ group did not (spearman rank-order correlations not significant; $p>0.05$), demonstrates the INJ group's inability to effectively attenuate shock at the ankle with increasing demand. It is not possible to determine if the ankle injury influenced the landing force or if the INJ group placed greater stress on the ankle in turn causing the injury from this data alone. ***Regardless, altered biomechanical characteristics during an explosive bilateral movement persist following an ankle injury, placing these individuals at greater risk of recurring ankle injuries or additional secondary lower extremity musculoskeletal injuries***. Though the varying amount of time between testing and when the injury occurred and the varying mechanisms causing the injuries are both limitations, this preliminary analysis demonstrates altered biomechanical characteristics persist. Following an ankle injury, subjects continue to land with excessive force, placing more load on the ankle during bilateral explosive movements. Further biomechanical analyses examining the entire kinetic chain is needed to fully understand all compensatory mechanics and better determine specific risks of additional injuries secondary to the primary ankle injury. The findings from this study translate directly to a variety of high injury risk populations. ***Over time, excessive landing forces and increased ankle moments coupled with the inability to effective attenuate shock with increased demand following an ankle injury may place these individuals at a higher risk for recurrent or secondary musculoskeletal injury***. Effective rehabilitation strategies may need to incorporate both ankle strengthening and improved landing biomechanical strategies focused on improving shock attenuation via eccentric control of the ankle joint, improving coordination of the ankle musculature and overall joint control during explosive movements.

Dominant Limb Lower Extremity Work Predicts Performance in Individuals with Low Back Pain

More than 80% of individuals will experience an episode of low back pain (LBP) at some time during their lives. In active populations, up to 37% of athletes suffer from LBP and military populations report 70% higher prevalence than the general population. Those who experience LBP tend to adapt their movement patterns to avoid painful positions while still successfully completing a task. During running individuals with low back pain exhibit increased knee stiffness and during walking, limb dominance has been reported to have an effect on lower extremity limb support in individuals with LBP. Though, no information exists on how LBP affects more advanced functional performance such as hopping or jumping, in highly active populations. Dominant limb dependence may lead to asymmetrical movement patterns that may impede their overall performance during more complex tasks. Increased joint stiffness in individuals with LBP may also reduce the power generating capability at that specific joint, thereby reducing the amount of positive work they are able to produce during explosive movements. The purpose of this project was to determine if there are differences in performance between those with low back pain and those without, and to determine if individuals with LBP demonstrated a greater dependence on the dominant limb than those without LBP during a stop jump task. We hypothesized that those with low back pain will have decreased jump height compared to controls and that lower extremity dominant limb work will be a better predictor of jump height in those with low back pain. Forty-three participants, 28 with a history of chronic low back pain (age 29.1±5.2yrs; height 1.78±0.06m; mass 85.4±9.0kg) and 15 healthy control participants (age 25.5±4.1yrs; height 1.81±0.05m; mass 84.9± 8.8kg), completed a double limb stop jump. Participants jumped forward onto two force platforms (Kistler Instrument Corp., Amherst, NY) from 40% of the subject's total body height. They were instructed to jump forward and then vertically as high as possible. Practice trials were given as needed and variables were averaged across three subsequent trials. Healthy control participants reported no history of back or lower extremity surgery, injuries, or back pain. The LBP group indicated they suffered from chronic LBP lasting at least six months and the first time in which they had to alter activity due to pain was an average 3.8 ± 3.3 years ago. All participants were currently highly physically active despite pain. Dominant limb was defined as the leg each subject would prefer to use to kick a ball. Raw vertical ground reaction forces (VGRF) were sampled at 1200 Hz and filtered using a fourth order low pass Butterworth filter with a cutoff of 50Hz. An eight camera three-dimensional motion capture system (Vicon Motion Systems Ltd, Centennial, CO) was used to collect lower extremity reflective marker data. Reflective markers were placed on the participants using a plug-in gait model to collect bilateral sagittal plane kinematics and kinetics at the hip, knee, and ankle. Kinematic data were sampled at 200 Hz and marker trajectories were filtered using a low pass Butterworth filter with a cut-off at 6Hz. Visual 3D (C-Motion, Germantown, MD) was used to calculate dominant and non-dominant ankle, knee, and hip work. Individual joint work was calculated by taking the integral of joint power curves from the power generation phase of the jump. Total lower extremity work was calculated by summing ankle, knee, and hip work values. Data were summarized using descriptive statistics including means and standard deviations. There was a significant difference in age between the LBP group and the control group (LBP: 29.2±5.2yrs; Control: 25.5±4.1yrs). Independent samples t-tests were used to examine differences in jump height performance and joint work during the stop jump between the LBP and control group. Paired samples t-tests were used to determine within group differences between dominant and non-dominant ankle, knee, hip, and total lower extremity work. Multiple linear regression models were constructed using a backwards stepwise method to predict jump height, in each group, from dominant and non-dominant ankle, knee, and hip work. Additionally, because age is a known confounding variable in those with LBP, it was entered into each final model. A significance level of alpha = 0.05 was used. All data analyses were conducted using SPSS (SPSS 22 IBM Corp, Armonk, NY). There were no significant differences within groups, between dominant and non-dominant ankle, knee, hip, and total work. There were no differences between groups in ankle, knee, and hip work or jump height. There was a significant difference in total lower extremity work (Figure 1) in the dominant (LBP: 2.80 ± 0.35J Control: 3.14± 0.50J; p=0.014) and non-dominant (LBP: 2.78 ± 0.33J, Control: 3.06 ± 0.45J; p=0.049) limbs, between the LBP and control group. In the low back pain group, the final model included dominant limb ankle work, knee work, hip work, and age. This model predicted 61.4% (p=0.0001) of the variance in the data. In the control group, the final model included non-dominant limb ankle work, hip work, and age, this model predicted 41.2% (p=0.032) of the variance in the data.

Figure 1: Bar graph representing individual joint work contributions in the low back pain and control group.



Our hypotheses were partially supported, in that there were no differences of jump height between groups, though the dominant limb was a strong predictor of jump height in the LBP group. Additionally, ***total lower extremity joint work was less in the LBP group compared to the control group, indicating that the LBP group may have small alterations at each joint, which collectively create a difference in lower extremity performance***. The different joint work variables that are present in the low back pain group model, compared to the control group model suggest that those with low back pain use a dominant limb dependence strategy to reach the same jump height as those without low back pain. ***The different lower extremity joint work strategies in individuals with low back pain may be from learned strategies and compensations due to pain that they have experienced for an extended amount of time***. This data indicates that limb dominance, may be driving lower extremity movement dysfunction in individuals with low back pain. Further, it has been indicated that those with LBP exhibit altered pelvis - trunk coordination during walking and running. ***This intersegmental coordination may be present further down the kinetic chain, beyond the pelvis***. Those with LBP have decreased total lower extremity joint work compared to individuals without LBP. Although functional performance may not be altered between those with LBP and those without, differing strategies to functional performance may exist. Dominant limb dependent strategies may cause asymmetrical mechanics which, over time, may lead to an increased risk of secondary lower extremity injury.

Landing Mechanics During a Stop Jump in Individuals with Low Back Pain and Low Back Injuries

The clinical presentation of low back pain (LBP) is highly variable, therefore it has been recommended that the spine be included with the lower extremities when conducting clinical and movement analyses. LBP is known to increase knee stiffness in runners, though information on how joint motion and loading rates may affect each other are unavailable. Likewise, the majority of research on LBP and low back injuries (LBI) has focused on back and trunk biomechanics, independent of the lower extremities. If those with LBP and/or LBI exhibit altered movement in the trunk, additional compensations may exist in the lower extremities, which may lead to the development of an injury in the lower extremity. The purpose of this study is to determine if physically active individuals with a history of LBP or LBI have altered landing mechanics in a double leg stop jump task, compared to healthy controls. We hypothesize that those with a history of LBP or LBI will have lower loading rates and different lower extremity sagittal plane kinematics at initial contact of a stop jump task, compared to healthy controls, and that such changes are related. Thirty-five subjects, thirteen with a history of LBP (age 26.7±4.1yrs; height 69.5±1.9in; mass 85.1± 7.3kg), nine with a LBI (age 28.1±3.6yrs; height 70.8±2.0in; mass 89.0±8.1 kg) and thirteen healthy control subjects (age 28.2±5.3yrs; height 70.1±2.2in; mass 85.8±9.9kg), completed a double limb stop jump. Subjects jumped forward onto two force platforms (Kistler Instrument Corp., Amherst, NY) from 40% of the subject's total body height. They were instructed to jump forward and then vertically as high as possible. Two practice trials were given and variables were averaged across three subsequent trials. Healthy control subjects reported no history of back or lower extremity injuries, or back pain. The LBP group indicated they suffered from chronic LBP lasting at least 6 months and the first indication of pain reported was an average 3.0 ± 2.4 years ago. The LBI group reported a physician diagnosed herniated disc or bulging disc in the lumbar section of the spine, with injury occurrence ranging from 2.3 ± 1.7 years prior. All subjects reported no pain at the current testing session and were all currently highly physically active. Raw vertical ground reaction forces (VGRF) were sampled at 1200 Hz and filtered using a fourth order low pass butterworth filter with a cutoff of 50Hz. A custom Matlab code (MathWorks, Natick, MA) was used to calculate loading rates from the VGRF. Peak loading rates were calculated from the onset of force, greater than 20N, to the initial peak VGRF and normalized to body mass. Subjects were outfitted with lower extremity reflective markers and an eight camera three dimensional motion capture system (Vicon Motion Systems Ltd, Centennial, CO) was used to collect bilateral sagittal plane kinematics at the hip, knee and ankle. Kinematic data were sampled at 200 Hz and marker trajectories were filtered using a Woltering filter with a predicted mean square error at 10mm. The plug-in gait model was used to calculate hip flexion at initial contact, knee flexion at initial contact and ankle flexion at initial contact. Data were summarized using descriptive statistics including means and standard deviations. Analysis of variance was used to compare the mean bilateral peak loading rates, knee flexion at initial contact, hip flexion at initial contact, ankle flexion at initial contact and peak VGRF, between the three groups. A significance level of alpha = 0.05 was used and post-hoc comparisons were conducted using the Bonferonni adjustment for multiple comparisons. Pearson Correlation Coefficients (r) between peak loading rates and lower extremity sagittal plane kinematics at initial contact and vertical ground reactions forces, in each group were also completed. All data analysis was conducted using SPSS (SPSS 22 IBM Corp, Armonk, NY). There were no significant differences in any sagittal plane lower extremity kinematics, VGRF, or peak loading rates between groups (Table 1.; $p>0.05$). In all groups VGRF were significantly correlated to peak loading rates, p<0.05, which was expected as peak loading rates are calculated from the VGRF curve. On the right limb, peak loading rate was significantly correlated to knee flexion at initial contact in the LBP group (r=.61; p=0.026) and to ankle flexion at initial contact in the LBI group (r=.75; p=0.019). All other correlations were not significant. Although there are significant correlations between sagittal plane landing at initial contact and peak loading rates, they do not support our initial hypotheses as there were no group differences. The correlation differences between right and left limbs, or possible limb dominance, could play into why we only saw significant correlations on the right side and not the left side. All but one subject, in the LBI group, were right limb dominant. ***This change in landing strategy between the LBP and LBI groups, from the control group, may be a compensatory strategy adopted due to pain or other mechanisms. If the shock from landing is not adequately distributed it may be an indicator for future injury.*** Though, in a task in which landing successfully is not the end goal, landing strategies and shock attenuation may change, as in this case the end goal is to vertically jump as high as possible. It appears that individuals with LBP and/or LBI are not loading different to that of healthy controls during the landing phase, in preparation for an explosive counter movement. The lack of differences may be due to the large between subject variability seen in different landing strategies displayed, and small sample sizes. Analyzing the take-off portion of the stop jump task may provide insight on how LBP and LBI may truly affect performance. Additionally, further research is needed to determine if landing strategies differ when subjects perform more impactful movements with a greater emphasis on shock absorption, like a single limb hop.

Table 1: Means and standard deviations of all variables by group. A negative ankle flexion value indicates ankle plantar flexion.

Variable	**Group**		
	Control Mean ± SD	LBP Mean ± SD	LBI Mean ± SD
Right VGRF (%BW)	228.80 ± 80.65	239.59 ± 95.91	206.02 ± 54.98
Left VGRF (%BW)	250.88 ± 110.27	237.14 ± 89.33	211.04 ± 65.90
Right Peak Load Rate (N/kg/s)	1598.00 ± 746.58	1617.45 ± 918.22	1232.84 ± 474.39
Left Peak Load Rate (N/kg/s)	1685.06 ± 792.60	1662.53 ± 979.82	1377.83 ± 420.61
Right Hip Flexion (deg)	54.57 ± 11.93	52.67 ± 14.52	54.58 ± 13.47
Left Hip Flexion (deg)	54.55 ± 11.58	52.94 ± 13.0	56.19 ± 13.23
Right Knee Flexion (deg)	39.45 ± 11.37	34.56 ± 10.02	41.46 ± 5.96
Left Knee Flexion (deg)	36.81 ± 11.29	34.59 ± 10.29	44.12 ± 8.51
Right Ankle Flexion (deg)	-6.97 ± 13.09	-9.16 ± 13.80	-10.19 ± 10.28
Left Ankle Flexion (deg)	-7.72 ± 18.22	-6.62 ± 14.95	-10.43 ± 17.09

Examining the Influence of Asymmetrical Knee Strength on Loading Patterns and Landing Mechanics during Different Dynamic Movements in MARSOC Personnel

Marine Corps Forces Special Operations Command (MARSOC) Operators and enablers are required to perform a multitude of complex tactical movements. Because musculoskeletal injuries to the lower extremity are very common in military forces it is important to understand the strategies used to attenuate shock during different dynamic tasks, providing insight into mechanisms associated with an increased risk of injury. Many studies have investigated landing characteristics for the purposes of injury prevention and rehabilitation due to higher incidence rates for lower extremity injuries and the potential for prevention through the modification of landing biomechanics. Human Service Support staff, including physical therapists, athletic trainers, and human performance coaches within MARSOC are currently developing injury prevention programs based on the most current evidence. Examining the biomechanical characteristics during landing tasks may further help assess injury risk and provide further evidence needed for the successful development of potential prevention and rehabilitation strategies. Therefore, the purpose of this analysis was to determine if MARSOC personnel demonstrated asymmetrical landing patterns in a variety of different landing tasks and examine how strength influences these specific landing strategies. Knee strength and lower extremity biomechanics collected from 224 United States Marine Raider operators, enablers, and students were included in this analysis. All subjects were cleared for full active duty at the time of testing. Isokinetic knee extension strength (KES) and knee flexion strength (KFS) were collected at 60° per second using an isokinetic dynamometer (Biodex Medical Systems Inc., Shirley, NY) and normalized to percent body weigth (%BW) for group comparisons. The FJSL task was performed with the subject standing 40% of their body height away from the edge of the force platform with a 30.5 cm hurdle positioned at 20% of their body height. Each subject was instructed to perform a double-leg jump over the hurdle, land with their foot on the center of the force platform, and maintain balance for approximately five seconds. The DLDL task began with the subject standing at the edge of a 76.2 cm high platform that was positioned directly behind the force platforms. The subject was instructed to “Drop off” the platform and land on both legs (one foot on each force platform). SLDL were completed in a similar manner. Each subject was asked to begin the trial standing one-legged on the edge of a 45.7 cm high platform and once instructed, drop off, landing on the same leg. Subjects were outfitted with reflective markers and lower extremity kinematics were collected using an 8-camera 3D motion capture system (Vicon Motion Systems Ltd, Centennial, CO) and vertical ground reaction forces were collected by two force plates at 1200 Hz (Kistler Instrument Corp., Amherst, NY). Data were processed with Vicon Nexus software using a Plug-in-Gait model. Marker trajectories were filtered using a Woltering filter with a predicted mean square error at 10mm. Peak vertical ground reaction forces (pkVGRF) along with sagittal plane hip, knee and ankle angles at initial contact (@IC) and peak flexion (pkFlex) for each limb were recorded from the kinematic analysis. Data were assessed for normality using Shapiro-Wilk tests. For data that were normally distributed Paired samples t-tests were used to evaluate lower extremity asymmetries in strength and landing mechanics between the dominant and non-dominant limbs. If the data were not normally distributed the Wilcoxon Signed Ranks test was used. Pearson correlation coefficients or Spearman’s rank order coefficients were used to examine the relationships between KES, mechanics during landing, and pkVGRF. All data were analyzed using SPSS (SPSS 22 IBM Corp, Armonk, NY). Significance level was set at alpha = 0.05. Paired samples t-test results (Table 1) indicate significant asymmetries in KES (p=0.001) but not in KFS (p=0.171) with the dominant limb KES approximately 6%BW stronger than the non-dominant limb KES. MARSOC personnel also demonstrated significant loading asymmetries during landing during all 3 landing tasks. There were also significant movement asymmetries for each of the different landing tasks. Pearson's correlation coefficients revealed significant relationships between landing mechanics and pkVGRF during each of the 3 different landing tasks. Though significant relationships between pkVGRF and kinematic measures were identified, none of the mechanical measures from the knee correlated to KES. The results from this analysis revealed that active duty MARSOC personnel demonstrated significant KES and landing asymmetries. MARSOC personnel demonstrated significant knee extension (predominantly quadriceps) strength asymmetries and landed with greater force on the dominant limb during all 3 landing tasks. These results may indicate a dominant limb dependence pattern exists and if this dominant limb dependence translates to other training movements, such as a squat and/or a deadlift, it could impact the individual's risk of both acute and chronic injuries. Though strength did not play a role in influencing landing mechanics during any of the landing tasks for either limb, further research is needed to understand how strength asymmetries may influence the performance of additional tasks such as rucking, weight training, or lifting heavy equipment. Current MARSOC human performance training programs utilize professional observation, verbal coaching of technique, and the incorporation of both unilateral and bilateral exercises all of which may help improve lower extremity strength symmetry. MARSOC personnel also demonstrated significant asymmetrical landing patters during the different landing tasks. Though statistically different, the significant mechanical asymmetries identified during landing (hip, knee, ankle angles) may not have much clinical relevance as the magnitude of the asymmetries was only a few degrees. The asymmetrical landing forces (pkVGRF) identified during all 3 of the tasks, however, could have a significant impact on MARSOC personnel, both acutely and cumulatively over time. Though the mechanical asymmetries between the dominant and non-dominant limbs may not be clinically relevant, the mechanical strategies used to absorb the impact during landing could have a significant role in reducing the risk of a variety of chronic lower extremity overuse injuries. ***Shock absorption strategies appear to differ between the different movements and may be influenced by the complexity of the task***. Simple bilateral landing tasks, similar to the DLDL, have distinct landing strategies that utilize all of the lower extremity joints. ***Coaching individuals on how to effectively attenuate shock by utilizing the ankle, knee, and hip may improve the overall quality of their landing and reduce the cumulative effects of the landing forces***. More complex movements that are unilateral requiring stabilization, such as the FJSL, appear to elicit a variety of different strategies, based on the lack of correlations. Incorporating a variety of complex dynamic movements into a performance training program may improve the individual's familiarity with complex movements while also applying the same shock attenuation concepts that they were coached on during the less complex movements. Movement patterns, including knee and ankle angles at initial contact and peak flexion significantly correlated to pkVGRF during both the DLDL and the SLDL. Increased knee @IC and increased knee pkflex during landing significantly reduced impact (pkVGRF) during the DLDL. Interestingly, though ***knee movement significantly improved shock attenuation, the movement about the knee was not influenced by maximal strength***. This indicates that factors other than strength play a role in movement control and shock attenuation. Strength training alone will not address the movement strategies needed to better absorb shock and reduce impact/injuries. Movement training focused on absorbing the shock with hip, knee, and ankle are needed to help reduce the cumulative effects of asymmetrical loading. Current MARSOC HP programs are incorporating movement and landing training into their programs. For example, the current MARSOC program ques participants “to land with their knees flexed and maintain that position” during some of their drop landing exercises. Because adequate shock absorption is related to the amount of movement at a joint during landing, HP coaches are also improving mobility and range of motion by incorporating a variety of dynamic and static stretches and also by having trained coaches identify individuals who may have mobility limitations and helping them address these previously unidentified issues. As participation rises within these programs, there may be an improvement in symmetry and reduction in the long-term effects of asymmetrical loading. Incorporating additional cueing that helps the participants focus on symmetrical weight distribution and utilizing the ankle during landing may further improve the program’s ability to reduce the long-term effects of these landing asymmetries. Future evaluations of individuals before and after the successful utilization of a MARSOC specific HP program along with long-term follow-up may help determine how successful these programs are at reducing both acute and chronic injury rates.

Productivity

A. Refereed Journal Articles (Appendices)
  a. Published
    i. Poploski KM, Picha KJ, Winters JD, Royer SD, Heebner NR, Lambert B, Abt JP, Lephart SM. Patterns and associations of shoulder motion, strength, and function in active full-duty MARSOC personnel. Mil Med. 2018; 183(11-12): e685-e692. doi:10.1093/milmed/usy088. *Previously submitted to the American Journal of Sports Medicine.*
    ii. Royer SD, Thomas DT, Winters JD, Abt JP, Best S, Poploski KM, Zalaiskalns AA, Lephart SM. Physical, physiological and dietary comparison between Marine Corps Forces Special Operations Command Critical Skills Operators and enablers. Mil Med. 2018; 183(11-12): e341-347. doi:10.1093/milmed/usy049. *Previously submitted to the Journal of Strength and Conditioning Research*.
  b. In Press
    i. Winters JD, Heebner N, Nagai T, Royer SD, Poploski KM, Randall C, Abt JP, Lephart SM. Altered Physical Performance Following Advanced Military Special Operations Tactical Training. *Journal of Strength and Conditioning Research.*
  c. In Review- Journal
    i. None
  d. In Review- MARSOC
    i. Influence of Limb Dominance and Shoulder Injury on Strength and Explosive Force in US Marines. *To be submitted to the American Journal of Sports Medicine*.
  e. Resubmission Preparation
    i. Human Performance Training Program Utilization and Training Outcomes in United States Marine Corps Forces Special Operations Command Operators. *To be submitted to Military Medicine*. *Previously submitted to the Journal of Strength and Conditioning Research*.
    ii. Epidemiology of Injuries in Combat Service Operators and Support Personnel in Marine Special Operations. *Previously submitted to Medicine and Science in Sports and Exercise*.
  f. Initial Preparation
    i. Lifestyle Risk Factors in US Marines: Is There a Relationship to Injury and Performance. *To be submitted to Military Medicine*.
    ii. Association between Knee Strength and Landing Biomechanics in Marine Corps Forces Special Operations Command Operators. *To be submitted to Clinical Biomechanics*.
    iii. Comparison of Physical and Physiological Characteristics based on Injury History. *To be submitted to the Orthopaedic Journal of Sports Medicine*.

B. Workshops and Conferences

a. Poploski KM, Winters JD, Johnson, Royer SD, Heebner NR, Abt, JP, Lephart SM. Decreased trunk strength and altered balance performance in Marines with chronic low back pain. Poster accepted for: The 2019 American Physical Therapy Association Combined Sections Meeting; January 23-26, 2019; Washington, DC
b. Johnson, AK, Winters JD, Poploski, KM, Heebner, NR, Lephart, SM, Abt, JP. Dominant limb lower extremity work predicts performance in individuals with low back pain. American Society of Biomechanics 42nd Annual Conference; August 8-11, 2018.
c. Best S, Bergin R, Royer S, Winters JD, Poploski K, Heebner N, Abt, JP, Lephart SM. Knee extension strength asymmetry does not affect peak power or fatigue during the Wingate test. American College of Sports Medicine Annual Meeting; May 29-June 2, 2018; Minneapolis, MN.
d. Royer SD, Winters JD, Poploski KM, Abt, JP, Zalaiskalns AA, Lephart SM. Training strategies maintain performance characteristics in Marines selected for Marine Corps Special Operations Individualized Training Course. American College of Sports Medicine Annual Meeting; May 29-June 2, 2018; Minneapolis, MN.
e. Picha K, Poploski KM, Winters JD, Heebner N, Abt, JP. Lephart S. The Relationship between flexibility and strength in Active Full-Duty Marines. Big Sky Athletic Training Sports Medicine Conference; February 4-8, 2018; Big Sky, MT.
f. Quintana C, Picha K, Poploski KM, Heebner N, Abt, JP. Lephart S. Lifestyle risk factors in US Marines: Is there a relationship to injury? Big Sky Athletic Training Sports Medicine Conference; February 4-8, 2018; Big Sky, MT.
g. Heebner N, Winters J, Poploski KM, Royer S, Abt, JP, Lephart S. Previous history of musculoskeletal injury is associated with lower physical performance in US Marines. Big Sky Athletic Training Sports Medicine Conference; February 4-8, 2018; Big Sky, MT.
h. Poploski KM, Winters JD, Picha KJ, Royer SD, Heebner NR, Lambert B, Getsy W, Abt, JP. Influence of limb dominance and shoulder injury on strength and explosive force in US Marines. American Physical Therapy Association’s Combined Sections Meeting; February, 2018; New Orleans, LA.
i. Winters JD, Johnson AK, Heebner NR, Abt, JP, Lephart SM. Individuals with a history of ankle injuries demonstrate altered biomechanical characteristics during a stop jump task. Orthopaedic Research Society; March, 2018; New Orleans, LA.
j. Best S, Abt, JP, Heebner N, Royer S, Winters JD, Poploski KM, Picha K, Johnson A, Marris S, Lephart SM. Human performance training program utilization and training outcomes in United States Marines special operations operators. International Congress of Soldier's Physical Performance. Nov 28-Dec 1, 2017; Melbourne, Australia.
k. Royer SD, Winters JD, Abt JP FACSM, Heebner NR, Poploski K, Getsy W. Williams N, Lephart SM. Physical and Physiological Comparison between Cohorts of Marine Corps Forces Special Operations Command Experienced and Entry Level Operators. American College of Sports Medicine Annual Meeting; May 30 – June 3, 2017; Denver, CO.
l. Johnson, AK, Winters, JD, Poploski, KM, Heebner, NR, Lephart, SM, Abt, JP. Strength and Biomechanical Contributions to Vertical Ground Reaction Forces in a

Single Limb Landing Task. American College of Sports Medicine 63rdAnnual Meeting. Denver, CO. 2017. Poster Presentation.

m. Winters JD, Johnson AK, Abt JP, FACSM, Heebner NR, Poploski KM, Lephart S, FACSM. Association between Rate of Torque Development, Strength, Landing Biomechanics, and Dynamic Postural Stability in Physically Active Males. American College of Sports Medicine; Denver, CO. June, 2017.
n. Johnson, AK, Winters, JD, Poploski, KM, Heebner, NR, Abt, JP. Landing Mechanics during a Stop Jump in Individuals with Low Back Pain and Low Back Injuries. American Society of Biomechanics 41st Annual Meeting. Boulder, CO. 2017.
o. Winters JD, Poploski KM, Johnson AK, Heebner NR, Abt JP. Dynamic Postural Stability and Landing Mechanics during a Single-Leg Landing in Individuals with a Previous Knee Injury. American Society of Biomechanics; Boulder CO. August, 2017.
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t. Royer SD, Winters JD, Abt, JP, FACSM, Heebner NR, Nagai T, Lovalekar M, Lambert B, Williams N, Lephart SM, FACSM. Physical and physiological comparison between Marine Corps Forces Special Operations Command Operators and Combat Support Personnel. American College of Sports Medicine Annual Meeting; May 31-June 4, 2016; Boston, MA.
u. Winters JD, Abt, JP, FACSM, Nagai T, Lambert B, Williams N, Heebner NR, Royer SD, Lephart SM, FACSM. Association between knee strength and landing biomechanics in Marine Corps Forces Special Operations Command Operators. American College of Sports Medicine Annual Meeting; May 31-June 4, 2016; Boston, MA.

Miscellaneous

Major Problems/Issues

1. Originally proposed aim- To measure the effectiveness of the MARSOC Performance and Resiliency human performance program to improve injury mitigating characteristics based on autonomic nervous system response
    a. Implementation of this technology to assess stress and recovery via autonomic nervous system response was ineffective, mainly due to a lack of operator or student compliance with using the device. At this time a broad implementation of this technology does not appear to be feasible, however, individual operators that are interested in using this technology and willing to maintain compliance may find some benefit if used with coaching staff.
2. Original aims to address specific gaps/needs developed in collaboration with prior Command. These same gaps did not exist for Command leadership at time of study execution. Discussions with CAPT Necia Williams and Mr. Bill Getsy suggested the need to reboot the research aims with particular focus on increasing the career longevity of the Operator. As a result, the next phase of research was developed with an overall purpose to develop and deliver a MARSOC-specific operational preparedness ranking system (M-SCOPE). The completion of these systematic tasks will allow for the development of an effective preparedness tool to addressing the capability gaps identified by MARSOC. Capability gaps were identified in collaboration with MARSOC and US Navy physiologists, taking into account the information provided by HSS staff members. The gaps were reviewed and prioritized during a meeting with MARSOC, SOCOM, US Navy physiologists, ONR, and UK. Additional meetings were held between prior to project commission to finalize the overall study design according to MARSOC training cycles, refine the test protocol to include new measures proposed by the investigators, metrics currently collected by MARSOC, and metrics required by SOCOM.

Technology Transfer

Not applicable

Foreign Collaborations and Supported Foreign Nationals

Dr. Nicholas Heebner (UK), in conjunction with Mr. Brad Lambert (MARSOC) was an invited speaker to the Special Operations Forces Human Performance Symposium in Ottawa from 09-10 MAY 2017. The symposium was hosted by the Canadian Special Operations Command. Dr. Heebner’s presentation was titled “Human Performance and Resilience of the Military Elite: From Lab to Land.”

Patents

Not applicable

Awards/Honors

Not applicable

Award Participants

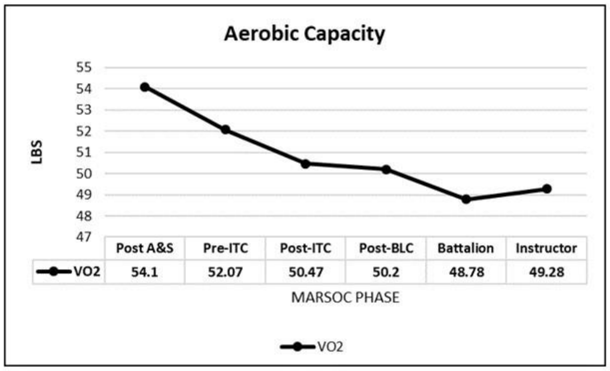
Not applicable

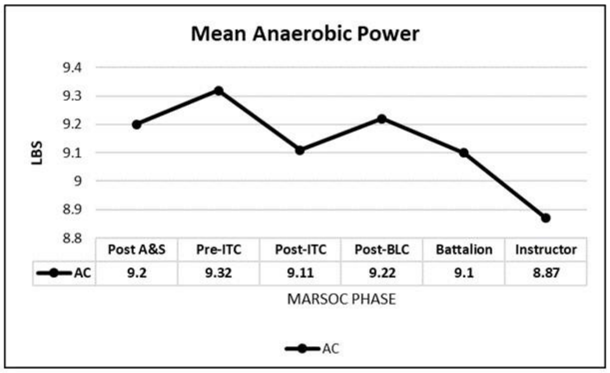
Summary

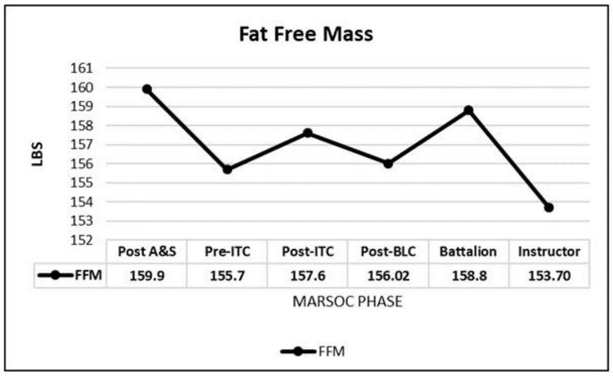
The objectives of this project were to measure the effectiveness of human performance programming implemented by Marine Corps Forces Special Operations Command (MARSOC) and provide necessary data to refine human performance training based on identified needs of the Force. A total of 680 participants were enrolled in this project for a total of 1019 participant encounters.

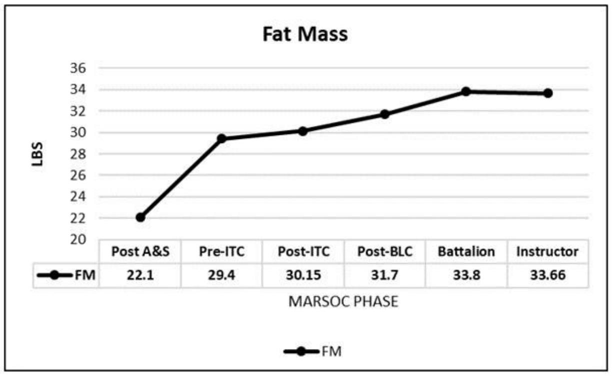
Human Performance Training Optimization

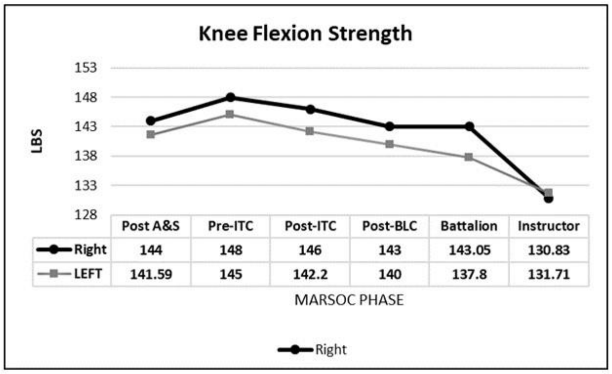
1. Five clinical trials were implemented to test the effectiveness of the human performance program. A total of 130 Marines completed pretesting measures across the five trials while only 92 completed posttesting measures. Recruitment predominantly focused on classes enrolled in Basic Language Course (BLC) to reduce overall attrition, which was 0-25% compared to the 24.1% and 94.4% for non-BLC trials. The BLC trials were prioritized due to the lower attrition, yet inconsistent and limited usage of human performance training was reported. Overall program utilization was 2.04±1.78 sessions/week during the first week, and continuously dropped to 0.93±1.39 sessions/week for the last week due to reported course demands.
2. Physical, physiological, and dietary differences were quantified between Operators and Combat Support Personnel/Specialists/Enablers. Operators demonstrated more efficient aerobic and anaerobic performance, greater strength, and relative fat free mass. No nutritional differences existed between groups yet poor fueling was identified for all participants.
3. Laboratory physiological and strength data during the different phases of a MARSOC career, such as A&S, Pre-ITC, Post-ITC, Post-BLC, and during non-phase specific Battalion and Instructor testing, show a marked decrease in fat free mass, aerobic capacity, anaerobic capacity, and lower extremity strength, performance variables critical to tactical performance and a decreased risk of injury.

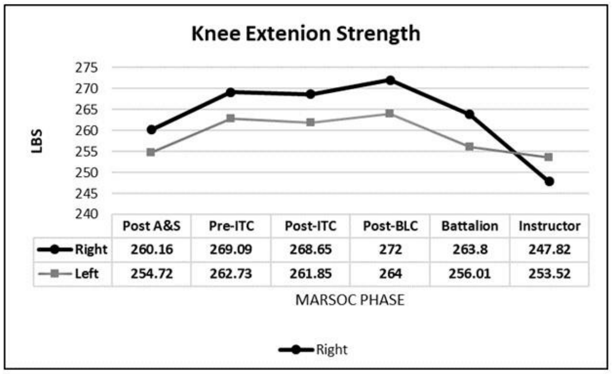












Injury Prevention

1. Self-reported injuries of the past 12 months for Operators were 37.3 total injuries per 100 person-years and 28.1 preventable injuries per 100 person-years. Total injuries for Combat Support Personnel/Specialists/Enablers were 28.8 injuries per 100 person-years and 21.2 preventable injuries per 100 person-years. An injury was defined as an event that limited full participation in tactical or physical training for a period of at least one day. Operators who do not participate in MARSOC human performance training are 0.8-2.1x more likely to sustain a musculoskeletal injury.
2. Lifestyle risk factors were identified relative to injury history. A model correctly classified 67.5% of cases and identified history of or current usage of tobacco as a significant predictor of injury.
3. Consistent with self-reported injuries, there was also a clear increase in MARSOC medical encounters for low back and shoulder from 2010 – 2015.

Mitigating Deficits from Previous Injury History

1. Marines who reported a prior injury during the last 12 months demonstrated poorer torso extension and knee flexion strength compared to non-injured Marines. Restoration of trunk extension and knee flexion strength are essential given the frequency of injury to the spine and lower extremity and the importance of these muscles to transfer load through the kinetic chain during multi-joint movements.
2. Marines with current, chronic low back pain demonstrated decreased trunk extension strength and altered balance performance on the dominant side when compared bilaterally and to matched controls.

3. Marines with a history of shoulder injury demonstrated decreased internal and external rotation strength compared to controls. Furthermore, MARSOC personnel with a history of injury to the nondominant shoulder performed differently than those with a dominant side injury, presenting with both strength and push-up asymmetries, indicative of deficits on the injured side. They also demonstrated significant ER strength deficits compared to controls. Those that reported a history of dominant shoulder injury did not demonstrate asymmetries, however, they may also continue to have deficits as healthy controls demonstrated greater strength and performance on their dominant side.
4. Marines with a history of concussion may have residual sensorimotor impairments despite displaying no residual symptoms from their previous concussion.
5. Operators with prior injury reported in the last year performed significantly worse than the non-injured Operators in the broad jump, 5-10-5 shuttle, and 300-yard shuttle

Recommendations

Human Performance Training Optimization

1. Although small improvements in strength and physiological performance were identified, physical training must be considered relative to other course or training-related requirements to improve compliance and determine what barriers prevent physical training opportunities.
2. CSO's and Enablers would benefit from dietary counseling which focuses on adequate fueling to support moderate-high intensity physical and tactical training. CSO's and Enablers both demonstrated carbohydrate intake that is significantly below the recommended intake for moderate-to high intensity training, while percent energy intake from fat was above the Dietary Reference Intake Acceptable Macronutrient Distribution Range.
3. Physical training strategies during the gap between Assessment and Selection and ITC may benefit from an increased emphasis on peak anaerobic power in conjunction with current recommendations. Students who were tested following Assessment and Selection and prior to the start of ITC maintained similar overall performance levels, however demonstrated deficits in anaerobic compared to previous studies (13.0 W/kg vs 12.65 W/kg respectively).
4. Identifying human performance training barriers and implementing increased supervised training is critical to maintaining high levels of tactical performance and decreased injury risk over the course of an Operators career.

Injury Prevention

1. Human performance/injury prevention training should be formalized for Combat Support Personnel/Specialists/Enablers to better match training evolution and tactical demands of Operators.
2. A needs analysis should be developed to determine specific physical and physiological thresholds required to effectively Operate as a member of an MSOT. Thresholds should be used to implement specific and directed training to meet these thresholds and increase the overall tactical capability of an MSOT. Compared to Enablers, CSO's demonstrated significantly greater physical and physiological performance, while the overall performance distribution of Enablers was highly variable. Deficits indicate Enablers are more likely to fatigue faster, and in conjunction with reduced strength, operational tasks such as rucking may present a much higher risk of musculoskeletal injuries, reducing the overall operational capability of an MSOT.
3. It is recommended that weight management counseling be initiated for subjects with body fat over 15% and that human performance programs target training to address VO_2 max and anaerobic capacity deficits at battalion. Previous research suggests a marked increase in injury count in Operators with body fat between 15-18% and a dramatic decrease in anaerobic and aerobic capacity in subjects over 15% body fat. For laboratory testing of Operators specifically at battalion, data indicates 62.5% of Operators are above 15% body fat, 82% have a VO_2 max below 55 ml/kg/min, and 48% have an anaerobic capacity below 9.2 W/kg, and 41% of the Operators are collectively suboptimal for body fat, VO_2 max, and anaerobic capacity.
4. Physical training should include sensorimotor exercises to promote joint stability and balance.

Mitigating Deficits from Previous Injury History

1. Our data has consistently shown that operators who have sustained previous injuries still exhibit deficits in either performance, strength, range of motion, balance, or landing mechanics. Although physical therapy is a critical component to complete recovery of any musculoskeletal injury our data and conversations with clinicians suggest that operators may not be maintaining rehabilitation compliance through to complete recovery. Collaborative strategies to formalize the integration of end stage rehabilitation to HP programming may help maintain a consistent conduit for complete recovery.
2. Multidisciplinary rehabilitation strategies should be investigated to mitigate post-concussion sequalae. Residual sensorimotor impairments; such as poorer dynamic motor control, may present a modifiable connection to the greater risk for lower extremity musculoskeletal injuries following concussion.

Appendices

1. Poploski KM, Picha KJ, Winters JD, Royer SD, Heebner NR, Lambert B, Abt JP, Lephart SM. Patterns and associations of shoulder motion, strength, and function in active full-duty MARSOC personnel. *Mil Med*. 2018; 183(11-12): e685-e692. doi:10.1093/milmed/usy088.

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3. Winters JD, Heebner N, Nagai T, Royer SD, Poploski KM, Randall C, Abt JP, Lephart SM. Altered Physical Performance Following Advanced Military Special Operations Tactical Training. *In Press at the Journal of Strength and Conditioning Research*.

4. Influence of Limb Dominance and Shoulder Injury on Strength and Explosive Force in US Marines. *To be submitted to the American Journal of Sports Medicine*.

5. Human Performance Training Program Utilization and Training Outcomes in United States Marine Corps Forces Special Operations Command Operators. *To be submitted to Military Medicine*. *Previously submitted to the Journal of Strength and Conditioning Research*.

6. Epidemiology of Injuries in Combat Service Operators and Support Personnel in Marine Special Operations. *To be submitted to Military Medicine. Previously submitted to Medicine and Science in Sports and Exercise*.

7. Lifestyle Risk Factors in US Marines: Is There a Relationship to Injury and Performance. *To be submitted to Military Medicine*.

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Patterns and Associations of Shoulder Motion, Strength, and Function in MARSOC Personnel Without History of Shoulder Injury

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Poster Presentation: The Relationship between Flexibility and Strength in Active Full-Duty Marines. Big Sky Athletic Training Sports Medicine Conference. February 4-8, 2018; Big Sky, MT.
Poster Presentation: Influence of Limb Dominance and Shoulder Injury on Strength and Explosive Force in US Marines. February 22-24; New Orleans, LA.

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Key Words: Military, Musculoskeletal, Shoulder, Injury Prevention

Abstract:

Introduction: Military personnel are at an increased risk of shoulder injuries due to training and deployment demands, however, there is a lack of information on the tactical athlete's upper extremity profile. Therefore, the purpose of this study was to examine shoulder musculoskeletal characteristics, including range of motion (ROM), strength, and function, and the relationships between these measures in Marine Corps Forces Special Operations Command (MARSOC) personnel without history of shoulder injury.

Materials and Methods: Participants included 195 full-duty male MARSOC personnel (age: 25.38 ± 2.85 years; height: 1.79 ± 0.06 m, mass: 82.79 ± 7.88 kg) without history of shoulder injury. Measurements of ROM, strength, and function were obtained bilaterally. Shoulder internal rotation (IR) and external rotation (ER) ROM were summed to calculate total arc of motion (ARC). Shoulder IR and ER strength were assessed using an isokinetic dynamometer. Function was evaluated with an explosive push-up.

Results: MARSOC personnel present with significantly increased ER ROM, and decreased IR ROM and ARC in their dominant shoulder. They demonstrated greater IR strength and peak force during the explosive push-up on the dominant side but no bilateral differences in average or peak rate were found. Correlation analyses suggest a weak inverse relationship between strength and ARC ($r = -0.15$ to -0.24). A positive relationship between strength and function were identified except for dominant IR strength and push-up variables. Those with the greatest ARC demonstrated significantly weaker IR and ER strength compared to those with less motion.

Conclusions: MARSOC personnel demonstrate shoulder ROM and strength symmetry patterns similar to overhead athletes. Increased dominant shoulder strength does appear to translate to a bilateral functional performance, but overall performance may be limited by the weaker nondominant upper extremity. As ARC increases, IR and ER rotation strength decrease. Repetitive, increased loading of the dominant shoulder during functional movements and training may increase risk of chronic, overuse-type injuries, common to the military. Unilateral exercises and movement analysis should be incorporated to encourage proper development of bilateral shoulder strength, which may be particularly important in those with high ranges of ARC.

Word count: 342

INTRODUCTION

The specialized roles of military personnel often require specific skills and high physical exertion, placing unique stresses on the shoulders and increasing the risk of injury.[1] In military populations, shoulder injuries account for a significant portion, approximately 8-24%, of musculoskeletal injuries, which are an enormous strain on the military in terms of financial cost and force readiness.[2-5] Due to intensive training and mission requirements, service members have been found to be at 5-18 times greater risk of shoulder instability injuries such as dislocations and subluxations compared to the general population and those with a history of shoulder instability are over five times more likely to reinjure.[6-9]

Susceptibility to instability injuries comes partially from the mobility the shoulder joint permits for functional movements[10] and is heightened in military populations due to the high demands and repetitive nature of the occupation. With the capsuloligamentous structures, the rotator cuff muscles serve as joint stabilizers as well as rotators of the shoulder.[11] Although disruption of strength and range of motion (ROM) of these structures has been identified in many shoulder injuries including subluxations, dislocations, labral tears, and rotator cuff tears, normal adaptations in these measures can be expected in populations that perform repetitive, demanding upper body tasks such as overhead athletes and military personnel.[12-15] For example, dominant/nondominant shoulder internal (IR) and external (ER) rotation ROM and strength asymmetries have been established in competitive uninjured athletes.[16-19] Overhead athletes typically present with greater ER and less IR ROM on their dominant extremity when compared to their nondominant side.[20,21] Additionally, increased strength of IR on the dominant extremity is common in healthy, athletic populations, while bilateral comparisons of ER strength seem to vary by sport and/or testing methods.[22,23] As many military roles also require specific skills and high physical demands, determining if similar patterns exist in uninjured military personnel is important to understand the typical presentation for this population.

Though studies of IR and ER ROM and strength are often conducted in parallel, few have investigated if there is an association between the two measures in the glenohumeral joint. In a preliminary study, Cibulka et al.[24] found that those with total arc of motion (IR+ER) greater than 165° demonstrated decreased IR and ER strength. As rotator cuff strength is important for stabilization of the shoulder, being able to quickly evaluate for deficits is valuable, particularly in military populations where clinicians are tasked with screening many individuals in a limited time period and often without access to specialized equipment. Clinicians commonly accept that individuals with excessive motion may not have ample strength to stabilize the joint,[24] however there is little evidence to support this or identify where in the range of motion strength deficits are of concern. If the relationship between shoulder ROM and strength can be more clearly defined, clinicians can use information from this assessment to not only determine if flexibility exercises are indicated but also screen for potential strength deficits, which require further evaluation and/or intervention.

Shoulder ROM and strength are important clinical measures, but the true indicator of function, particularly in a military setting, is performance on dynamic, tactically relevant tasks. Numerous studies have linked rotator cuff strength with sports specific performance.[25-27] as well as functional exercises such as bench press, rows, and medicine ball toss.[28,29] Military physical and tactical training often require explosive, powerful movements such as those needed during tasks ranging from plyometric push-ups to hand-to-hand combat. Standard and plyometric push-ups require significant activation of the rotator cuff musculature.[30-32] Determining the relationship between shoulder strength and functional performance in a healthy military population will help to understand injury mechanisms and deficits in injured individuals. For example, if military personnel are asymmetrical in shoulder strength like overhead athletes, then they may be overloading their dominant side during bilateral tasks. Chronic overloading of one shoulder may place the individual at risk of overuse injury. Similarly, although occupation habits of using the same side to complete tasks may produce strength asymmetries, situations may arise where they need to execute a task on their non-dominant side, potentially placing them at increased risk for injury.

The physical demand and therefore the risk of injury have been found to be even greater in special operations communities,[1] such as the Marine Corps Force Special Operations Command

(MARSOC). While all deployable MARSOC Marines must be prepared for mission demands, typically Operators complete the most rigorous selection process and training. As MARSOC Operators, students, and selectees (furthermore referred to as MARSOC personnel) are all part of a specific career path and must meet specified physical standards, understanding shoulder function in this group is needed to determine true deficits in injured individuals and to identify those at risk of new and recurrent injuries.

Therefore, the purpose of this study was to examine shoulder musculoskeletal characteristics of active full-duty MARSOC personnel without a history of shoulder injury to determine potential patterns placing this population at further risk of injury. Specifically, 1) determine if bilateral differences exist in strength and range of motion, 2) examine if asymmetries translate to dynamic function, and 3) determine the relationship between these measures in a population at high risk for shoulder injuries. We hypothesize that, with the significant upper body demands required of these individuals, asymmetries similar to those found in overhead athletes will exist. Furthermore, we hypothesize that there will be an inverse relationship between ROM and strength and a positive association between strength and force production during an explosive push-up task.

METHODS

Participants

All participants were asked to limit any strenuous physical training, avoid caffeine, nicotine, and alcoholic beverages twenty-four hours prior to testing. Approval was obtained for all research procedures from the University's Institutional Review Board. Written informed consent was obtained from each subject prior to participation in the study.

Participants in this study were extracted from a larger longitudinal MARSOC initiative from August 2015 to July 2017. Inclusion criteria included being a MARSOC Operator, student, or selectee in training to become a MARSOC Operator cleared for full and unrestricted participation in physical and tactical training. Participants were excluded if they reported ever sustaining a shoulder injury that caused them to stop or modify training or physical activity for at least one full day (n = 160). Participants that did not complete at least shoulder flexibility, strength, and injury history were excluded as well (n = 90). A participant may not have completed all tasks due to reasons such as limited time or pain with assessment. Therefore, a total of 195 full-duty male Marines (25.38 ± 2.85 years, 1.79 ± 0.06 m, 82.79 ± 7.88 kg) were included in this research analysis. Participants included 50 active MARSOC Operators as well as 29 students and 116 selectees in training to become MARSOC Operators with an average of 5.37 years of military experience (range 2.3-16.5 years). One-hundred eighty-one participants were right hand dominant, 14 were left hand dominant.

Laboratory Data

Range of Motion

Passive shoulder IR and ER ROM were examined bilaterally. Subjects were positioned supine with the testing extremity placed in 90° of shoulder abduction, 90° elbow flexion, and the forearm in neutral. A small pad was placed under the humerus to ensure motion in the correct plane. The scapula was stabilized as in previous studies.[33,34] Reliability of these measurements has previously been established.[35] Two researchers completed all ROM measurements with one completing the passive shoulder movement for all participants and the other measuring the angle of each assessment for all participants. Measurements of IR and ER were collected from this standardized position using a goniometer. Three trials within 3 degrees of each other were collected and then averaged for each ROM measurement. Total arc of motion (ARC) was calculated by adding the average ER + IR ROM for each shoulder.

Strength

Shoulder IR and ER strength were evaluated bilaterally on an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY). Isokinetic strength testing on the Biodex has been found to be a reliable and valid strength measure.[36] Subjects were seated with shoulders placed in a modified neutral position of 15-20° abduction and 15-20° flexion. Subjects were positioned and stabilized according to manufacture specifications. Warm-up and familiarization trials were performed as standard procedure. Strength was determined by the average of 5 repetitions and analyzed relative to body weight. All repetitions were concentric-concentric at 60 degrees/second.

Dynamic Function

To evaluate dynamic shoulder function, an explosive push-up task was used. Participants started in a prone position with elbows bent placing each hand on a separate force plate at approximately chest level. The force plates were mounted flush with the surrounding custom-built flooring so feet and hands were level. Participants were instructed to keep both back and legs straight, feet together, and elbows in a neutral position. When the researcher instructed “rise-up,” the participant lifted his chest approximately one inch off the ground. Once this position was reached, the researcher immediately instructed “go,” at which time the participant performed an explosive push-up, pushing completely off the force plates. The participant was instructed that the goal of the task was to perform the most explosive push-up possible. Participants were given at least one practice trial, followed by three collected trials. A similar protocol has previously been described with excellent relative reliability (ICC= 0.91- 0.96).[37]

Vertical ground reaction force (VGRF) data were collected at 1200 Hz using Vicon Nexus Software (Vicon Motion Systems, Centennial, CO). The two force plates’ (Type 9286BA, 60 cm × 40 cm platform; Kistler Instrument Corp., Amherst, NY) VGRF analog signals were low-pass filtered with a Butterworth fourth-order zero-phase-shift lag with 50 Hertz cut-off using C-Motion Visual 3-D (C-Motion, Germantown, MD). All data processing was completed in C-Motion Visual 3-D and output variables included peak VGRF (Peak Force) during the concentric phase of the push-up movement, peak rate of force production (Peak Rate) and average rate of force production (Avg Rate). Peak Rate was defined as the highest speed between the start of the movement and peak force, and was calculated by identifying the peak of the first derivative of the VGRF. Avg Rate was defined as the rate of change in the force between the start of the movement and the peak force, and was calculated as the mean of the first derivative of the VGRF. The three trials were averaged for each variable (Peak Force, Peak Rate, and Avg Rate) for each side and normalized to body weight by dividing by mass.

Statistical Analysis

All variables were assessed for normality and frequency distribution. The mean and standard deviation (SD) were calculated for each parametric measure; median and interquartile range were calculated for each nonparametric variable. Paired-samples *t*-tests for parametric data and Wilcoxon Signed Ranks Tests for nonparametric data were used to analyze between-limb differences. To determine the relationship between ROM and strength, as well as strength and push-up variables, Spearman's rank-order correlations were used for analysis.

To determine if those with greater ROM demonstrated strength or function differences, participants were categorized into four quartiles (Q1, Q2, Q3, Q4) based on ARC. Analyses were completed separately for dominant and nondominant sides. Kruskal-Wallis Tests with post-hoc pairwise comparisons using a Bonferroni correction for multiple comparisons were completed to assess strength and performance differences between quartiles. Independent *t*-tests and Mann-Whitney *U* tests were used to determine strength and function differences between ARC quartiles Q4 and Q1/2 for parametric and nonparametric variables respectively. Again, separate analyses were completed for the dominant and nondominant sides.

An alpha level of 0.05 was set prior to denote statistical significance for comparison. Statistical analyses were performed with IBM SPSS Statistics Version 22 (IBM Corp, Armonk, NY).

RESULTS

The results indicate MARSOC personnel without a history of shoulder injury present with significantly greater ER ROM, and less IR ROM and ARC on their dominant shoulder ($P \leq 0.001$, $P \leq 0.00$, $P = 0.003$ respectively). Strength was found to be greater in IR on the dominant shoulder compared to non-dominant ($P < 0.001$), but symmetrical in ER (*P* = 0.137). Peak Rate and Avg Rate were symmetrical between dominant and nondominant shoulders, while Peak Force was significantly greater on the dominant side (*P* = 0.037) during the explosive push-up (Table 1).

Correlation analysis indicates a significant negative correlation exists between ARC and IR and ER strength on both the dominant and nondominant sides (r = -0.15 to -0.24; Table 2). To address the relationships between strength and function, IR and ER strength data were analyzed with bilateral push-up data. Findings indicate significant positive correlations between dominant ER and nondominant IR and ER strength and bilateral push-up variables (ranging from r = 0.21 to 0.41), but no relationship between dominant IR strength and push-up variables. Table 3 displays these relationships.

No significant differences were found for push-up variables between ARC quartiles for the dominant or nondominant side (*P* > 0.05). No differences in IR or ER strength were found between Q1 and Q2, Q2 and Q3, or Q3 and Q4 for either side (*P* > 0.05; Figures 1A,B). On the dominant side, Q4 demonstrated significantly weaker ER than Q2 and weaker IR strength than Q1 and Q2 (*P* < 0.05). On the nondominant side, Q4 demonstrated significantly weaker ER strength than Q1 (*P* = 0.049).

Based on the significant differences found between Q4 and Q1 and Q2 noted above, and the relatively small range of ARC captured by Q3, approximately 6° for both dominant and nondominant sides, very near the accepted 5° standard of error for goniometry,[38] analysis of Q4 and Q1+2 allows for comparison of two distinct groups. Those with the greatest ARC, Q4, demonstrated significantly weaker IR and ER strength compared to Q1+2 (*P* < 0.05) on both the dominant and nondominant sides (Figure 1AB; Tables 4 and 5).

DISCUSSION

The results of this study support our hypothesis that similar ROM patterns portrayed in overhead athletes are also present in MARSOC personnel. On the dominant shoulder, MARSOC personnel present with greater ER ROM and lesser IR ROM and ARC. Likewise, tennis, handball, and baseball players also display this same pattern.[21,34,39-43] Additionally, a study conducted by Vairo et al.[44] found that military cadets demonstrate greater active and passive ER and less IR on their dominant extremity indicating agreement that in military populations differences in ROM may exist between extremities. Also consistent with the findings in overhead athletes, MARSOC personnel demonstrated significantly stronger IR strength on the dominant side.[22,45] Symmetrical ER strength found in our study is similar to findings in other athletes but may be specific to certain populations and/or assessment methods as a uniform pattern has not been identified.[19,23,45,46] Despite differences in physical demands, ROM and strength patterns similar to overhead athletes suggest adaptations of the upper extremities also occur in this population to meet training and physical demands.

Interestingly, increased dominant side explosive force was evident in the explosive push-up as Peak Force was significantly higher on the dominant side. Both Peak Rate and Avg Rate were symmetrical, however, suggesting that the dominant side shoulder pushes more load than the nondominant shoulder but just as quickly. Though differences in bilateral Peak Force were small, only 0.12 N/kg on average, over time this may contribute to overuse injuries as research suggests that many injuries stem from small amplitude, repetitive, and cumulative overloading often required during physical activity or occupational tasks.[3]

As described, researchers have investigated the relationship between rotator cuff strength and performance.[25-29,47] Although prior to this study, few, if any, have specifically investigated the association between rotator cuff strength and explosive push-up performance, activation of internal and external rotator cuff musculature during both standard and dynamic push-ups has been confirmed through electromyography studies.[30-32,48,49] Though the internal rotators' involvement is more intuitive due to the movement pattern, the relatively high activity of the external rotators, specifically the infraspinatus, is attributed to its stabilizing role during weight-bearing dynamic tasks.[30] The data partially supported our hypothesis that a positive association between strength and force production during the explosive push-up exists. Higher performance on the push-up, as measured by greater Peak Force, Peak Rate, and Avg Rate, was associated with greater bilateral ER strength and nondominant IR strength. Dominant IR strength was not associated with any of the push-up performance variables. From a performance perspective, as dominant IR strength was significantly stronger, this lack of dominant side strength/ function association suggests that performance on a bilateral, synergistic task may be limited by the strength of the weaker, nondominant side. From an injury risk standpoint, although true dominant side maximal strength may only be evident during unilateral or dissociated tasks, the cumulative reliance on the dominant side may increase risk of overuse injury as previously discussed.

Both increased and decreased glenohumeral ROM have been associated with injury.[50-52] Differences in these findings may be due to differences in pathology. For example individuals with impingement have been found to present with ROM deficits, while those with rotator cuff tears or instability often have ROM gains.[12] The findings from the correlation analysis demonstrated an inverse relationship between ROM and strength, suggesting increased dominant and nondominant ARC are associated with decreased IR and ER strength. Cibulka et al.[24] used a nonparametric classification and regression tree (CART) analysis to determine that those with ARC greater than 165° exhibited significantly weaker IR and ER strength. Although this cut-off may provide a guideline, as a preliminary study they did not differentiate between dominant and nondominant sides and the subjects were mostly females, important considerations as typical ROM and strength ranges are influenced by limb dominance, sex, and activity level.[53-55] Due to these differences between populations, determining a consistent degree where strength decreases may not be possible. More broadly our findings suggest that as ARC increases, those with the highest ranges of motion likely have significantly decreased strength. Just as clinicians often prescribe specific stretching exercises if assessment reveals limited ROM, in those with higher ranges of ARC, clinicians can then use their clinical knowledge and assessment skills to more thoroughly evaluate rotator cuff strength and prescribe shoulder stabilization and strengthening exercises as indicated. Though this a common notion among clinicians, there has been little evidence to support this concept in the past. Given the high-risk of shoulder injuries in the population, force-wide prevention programs may be best, but if environmental factors do not permit, this may be a valuable screening tool.

While flexibility, strength, and function are important intrinsic factors that may predispose or protect an individual from injury, it is important to consider that injury susceptibility is likely a multifactorial interaction of intrinsic and extrinsic factors.[56] Furthermore, the contribution of factors may differ depending on type of injury. For example, numerous studies have found preseason IR and ER strength and muscle imbalances to be risk factors for injury in athletic populations.[50,57,58] In contrast, in a prospective study of students at the United States Military Academy, rotator cuff strength was not found to be a risk factor for instability injuries.[59,60] However, only acute subluxations and dislocation events were included in this analysis, likely excluding most overuse and chronic conditions.[10] Understanding the presentation of individuals without history of injury helps clinicians to determine true deficits in injured individuals. Given the asymmetries found in uninjured Marines in this study, dominant to nondominant side comparison may not be sufficient for clinical decision making such as determining appropriateness for surgery, evaluating gains during rehabilitation, or clearing patients for return to duty following a shoulder injury. Instead, the established normative ranges and relationships can be used to drive an evidence-based course of care. Given the often uncontrollable extrinsic factors such as volume, intensity, and inherent environmental risks of training and deployments for Special Forces military members,[1] further studies are needed to assess the relationship between flexibility, strength, and function in those with previous and current injuries, as well as prospectively analyze these findings as risk factors for specific shoulder pathologies and re-injury.

The current study does have some limitations. A significant portion of our participants were students or selectees. These individuals likely have not experienced the same demands as seasoned Operators; however it may be difficult to obtain a large group of Operators without any history of shoulder injury. Additionally, many of our participants participated in athletics in either high school or college. As 84% of participants had previous exposure to sports such as football, baseball, or wrestling, these participants may have already had adaptations prior to joining the military.

CONCLUSIONS

MARSOC personnel without a history of shoulder injury demonstrate shoulder adaptations in ROM and strength similar to overhead athletes. Overall functional performance may be limited by the weaker nondominant upper extremity and increased loading of the dominant shoulder may increase risk of overuse injuries. The job demands of Operators and students often cannot be altered, therefore, physical training must address these deficits, even in uninjured personnel. Considering the high rate of shoulder injury in this population, encouraging participation in prevention programs which incorporate unilateral shoulder exercises to eliminate dominant side compensation, as well as movement and loading assessment during bilateral functional tasks to ensure both the dominant and non-dominant shoulders are contributing equally, may reduce overuse injuries while improving tactical performance. Targeted shoulder stabilization and strengthening may be particularly important for those with high ranges of ARC. Additionally, when treating a patient following injury, clinicians may use the established normative ranges and relationships to direct care instead of relying on non-injured extremity presentation. While prevention of injuries is the primary goal, in highly demanding environments, mitigation as well as successful return to duty following injury are essential for ensuring force readiness as well as individuals' career longevity and overall improved quality of life.

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Table 1. Bilateral Comparison

	N	Dominant UE	Nondominant UE	*P* value
Shoulder Strength (Nm/kg)				
IR§	195	0.64 (0.15)	0.60 (0.13)	<0.001*
ER	195	0.43 ± 0.06	0.43 ± 0.06	0.137
Shoulder Flexibility (°)				
IR§	195	48.33 (9.00)	55.33 (9.35)	<0.001*
ER§	195	102.33 (10.00)	95.33 (11.00)	<0.001*
Total Arc	195	150.65 ± 9.57	152.20 ± 9.50	0.003*
Explosive Push-up				
Peak Force§ (N/kg)	87	6.11 (0.90)	6.02 (1.05)	0.037*
Average Rate of Force Production§ (N/kg/s)	87	17.57 (9.54)	17.89 (9.39)	0.899
Peak Rate of Force Production§ (N/kg/s)	87	36.94 (19.05)	37.26 (20.47)	0.846

§ Indicates non-parametric data; values expressed as median (interquartile range). For all others mean ± standard deviation is presented. UE, upper extremity; IR, internal rotation; ER, external rotation; Nm/kg, newton-meters per kilogram; N/kg, newtons per kilogram; N/kg/s, newtons per kilogram per second.

*Significantly different between dominant and nondominant UE ($P < .05$).

Table 2. Strength and Flexibility Correlations

		Shoulder Flexibility					
		Dominant UE			Nondominant UE		
		IR	ER	Arc	IR	ER	Arc
Shoulder Strength	Dom IR	-0.076 (0.289)	-0.248* (<0.001)	-0.235* (0.001)			
	Dom ER	-0.044 (0.545)	-0.168* (0.019)	-0.167* (0.019)			
	Nond IR				-0.063 (0.379)	-0.086 (0.235)	-0.146* (0.042)
	Nond ER				-0.130 (0.071)	-0.094 (0.192)	-0.203* (0.004)

Values expressed as Spearman's Rank Order Correlation (*P* Value). UE, upper extremity; Dom, dominant; Nond, nondominant; IR, internal rotation; ER, external rotation.

*Significant correlation ($P < .05$), also shaded gray for clarity.

Table 3. Strength and Push-up Correlations

		Shoulder Push-up					
		Dominant UE			Nondominant UE		
		Peak Force	Peak Rate	Average Rate	Peak Force	Peak Rate	Average Rate
Shoulder Strength	Dom IR	0.055 (0.611)	0.115 (0.288)	0.119 (0.271)	0.159 (0.142)	0.155 (0.152)	0.179 (0.097)
	Dom ER	0.277* (0.009)	0.313* (0.003)	0.321* (0.002)	0.270* (0.011)	0.326* (0.002)	0.306* (0.004)
	Nond IR	0.160 (0.139)	0.211* (0.050)	0.194 (0.072)	0.264* (0.014)	0.243* (0.023)	0.244* (0.023)
	Nond ER	0.272* (0.011)	0.301* (0.005)	0.347* (0.001)	0.406* (<0.001)	0.393* (<0.001)	0.395* (<0.001)

Values expressed as Spearman's Rank Order Correlation (*P* Value). UE, upper extremity; Dom, dominant; Nond, nondominant; IR, internal rotation; ER, external rotation.

*Significant correlation ($P < .05$), also shaded gray for clarity.

Table 4. Groups Split Based on Dominant Total Arc

	N	**High Group** 4th Quartile ARC > 156.83°	N	**Control Group** 1^{st} & 2^{nd} Quartiles ARC ≤ 151°	*P* value
IR Strength (Nm/kg)	49	0.61 ± 0.08	98	0.68 ± 0.14	<0.001*
ER Strength (Nm/kg)	49	0.41 ± 0.06	98	0.44 ± 0.06	0.002*
Peak Force (N/kg)	27	6.32 ± 0.76	37	6.18 ± 0.64	0.419
Average Rate§ (N/kg/s)	27	17.98 (10.17)	37	17.57 (9.73)	0.292
Peak Rate§ (N/kg/s)	27	36.33 (24.04)	37	37.89 (20.15)	0.492

§ Indicates non-parametric data; values expressed as median (interquartile range). For all others mean ± standard deviation is presented. ARC, total arc of shoulder motion; IR, internal rotation; ER, external rotation; Nm/kg, newton-meters per kilogram; N/kg, newtons per kilogram; N/kg/s, newtons per kilogram per second.
*Significantly different between groups ($P < .05$).

Table 5. Groups Split Based on Nondominant Total Arc

	N	**High Group** 4th Quartile ARC > 158.0°	N	**Control Group** 1st & 2nd Quartiles ARC ≤ 152.3°	*P* value
IR Strength (Nm/kg)§	47	0.58 (0.11)	102	0.62 (0.16)	0.03*
ER Strength (Nm/kg)	47	0.41 ± 0.06	102	0.44 ± 0.06	0.01*
Peak Force (N/kg)	29	6.00 ± 0.60	38	6.15 ± 0.60	0.318
Average Rate (N/kg/s)§	25	15.94 (10.47)	38	18.65 (8.77)	0.574
Peak Rate (N/kg/s)§	25	37.00 (20.05)	38	37.31 (15.94)	0.888

§ Indicates non-parametric data; values expressed as median (interquartile range). For all others mean ± standard deviation is presented. ARC, total arc of shoulder motion; IR, internal rotation; ER, external rotation; Nm/kg, newton-meters per kilogram; N/kg, newtons per kilogram; N/kg/s, newtons per kilogram per second.

*Significantly different between groups ($P < .05$).

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Physical, Physiological, and Dietary Comparisons Between Marine Corps Forces Special Operations Command Critical Skills Operators and Enablers

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ABSTRACT Introduction: Tactical demands of a Marine Corps Forces Special Operations Command (MARSOC) Critical Skills Operator (CSO) require high levels of physical performance. During combat deployments, teams of CSOs are supplemented with enablers who specialize in mission-specific tasks. MARSOC CSOs and enablers serve alongside each other in extreme combat environments, often enduring the same physical demands, but the selection process for each group is very different. The purpose of this observational study was to quantify the physical, physiological, and dietary differences of MARSOC CSOs and enablers, as this may have a direct impact on tactical performance and provide important information to shape future research. Materials and Methods: Fat free mass (FFM), fat mass (FM), fat mass index (FMI), fat free mass index (FFMI), anaerobic power (AP), anaerobic capacity (AC), aerobic capacity (VO_2max), knee flexion (KF), knee extension (KE), trunk extension (TE), and trunk flexion (TF) isokinetic strength were collected. Dietary intake was collected using automated self-administered 24-hr dietary recalls (ASA24) for a subgroup of subjects. Results: Testing on 164 male CSOs (age: 27.5 ± 3.8 yr, height: 178.7 ± 6.5 cm, mass: 85.7 ± 9.1 kg, and 7.6 ± 2.9 yr of military service) and 51 male enablers (age: 27.8 ± 5.4 yr, height: 178.4 ± 8.5 cm, mass: 83.8 ± 11.8 kg, and 7.9 ± 5.4 yr of military service) showed there were no significant differences for age, height, mass, or years of military service. ($p > 0.05$). CSOs demonstrated greater physiological performance in AP (W/kg) ($p = 0.020$), AC (W/kg) ($p = 0.001$), and VO_2max (ml/kg/min) ($p = 0.018$). There were no significant differences in FM and FFM ($p > 0.05$), however CSOs demonstrated significantly higher FFMI ($p = 0.011$). CSOs also demonstrated greater KF (%BW) ($p = 0.001$), KE (%BW) ($p = 0.001$), TE (%BW) ($p = 0.010$), and TF (%BW) ($p = 0.016$). No differences in energy or macronutrient intake were observed in the subgroup. Conclusions: MARSOC CSOs demonstrated significantly greater FFMI, AP, AC, VO_2max, KF, KE, TE, and TF compared with enablers. Dietary intake was consistent between groups, but fueling concerns were identified for all personnel in the subgroup. These findings suggest the need for future studies to examine what physiological and strength thresholds are necessary to operate effectively as a member of a MSOT and determine the relationship between specific performance deficits and risk of injury. In addition, the integration of nutrition strategies that augment and optimize the performance of both CSOs and enablers may be beneficial.

INTRODUCTION

U.S. Special Operations Forces (SOF) have a challenging occupation, often requiring personnel to perform at their maximal physical and physiological capacity.[1] SOF are assigned to specialized military missions, requiring variable and unpredictable levels of strength, power, and endurance, while also presenting unique metabolic challenges, including matching nutrient needs with fuel demands.[2,3] SOF operations, or tasks within an operation can range from long-duration, low intensity, aerobic based tasks, to short-duration, high-intensity anaerobic tasks. These wide variations in task demand require multifaceted strength, power, and endurance capabilities in conjunction with sufficient nutritional intake to fuel periods of high-intensity and/or extended moderate intensity physical activity.[4,5] In addition to task performance improvements, high levels of aerobic fitness and strength correlate with reduced risk of musculoskeletal injury.[6–8] Reducing the incidence of musculoskeletal injury in SOF is critical to ensure tactical readiness and availability for deployment.[9]

The United States Marine Corps Forces Special Operations Command (MARSOC) deploy Marine Special Operations Teams (MSOTs) that consist of Critical Skills Operators (CSOs) and enablers. CSOs are highly trained in combat skills and tactics in order to complete a wide variety of complex military operations. Enablers supplement CSOs during deployments and operations by providing specialized skill sets ranging from medical care, to intelligence and communications.[10] As a MSOT, CSOs and enablers operate alongside each other in tactical situations, often enduring the same physical task demands. Although CSOs and enablers deploy as a unit, the selection process and training of CSOs and enablers are very different. The assessment and training to become a CSO are exhaustive, requiring

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high levels of tactical and physical performance, while an enablers' selection is primarily based on military occupational specialty and less on physical or tactical performance. Regardless, performance deficiencies among enablers have a similar impact on force readiness and MSOT capability.

CSOs and enablers are both critical components of an MSOT and absence or inefficient performance due to suboptimal physical conditioning or injury may be detrimental to special operations missions by reducing the overall capability of a MSOT. Therefore, the purpose of this observational study was to quantify the differences in physical, physiological, and dietary characteristics between MARSOC CSOs and enablers as this may have a direct impact on the tactical capability of a MSOT. This information will help identify team specific weaknesses and provide data that will assist in the advancement of training programs and selection processes to help improve overall MSOT performance and the prevention of injuries.

METHODS

Subjects

A total of 164 male CSOs (age: 27.5 ± 3.8 yr, height: 178.7 ± 6.5 cm, mass: 85.7 ± 9.1 kg, and 7.6 ± 2.9 yr of military service) and 51 male enablers (age: 27.8 ± 5.4 yr, height: 178.4 ± 8.5 cm, mass: 83.8 ± 11.8 kg, and 7.9 ± 5.4 yr of military service) were recruited to the study (Table I). Inclusion criteria included clearance for full and unrestricted participation in physical and tactical training, and no history of musculoskeletal injury within the past month that led to training cessation or medical treatment. Subjects were also asked to limit any strenuous physical training, avoid caffeine, nicotine, and alcoholic beverages 24 h prior to testing. The study was approved by the University of Kentucky's Institutional Review Board. Written informed consent was obtained from each subject prior to participation in the study.

Study Design

This study was an observational analysis. Subjects completed a 1-d laboratory protocol that consisted of an all-encompassing performance assessment. A subgroup completed a 24 h dietary recall. All laboratory assessment categories were completed in the following order: anthropometrics, anaerobic performance, strength, dietary assessment, and aerobic capacity.

TABLE I. Subject Characteristics

	CSOs			Enablers			
	n	Mean	SD	*n*	Mean	SD	*p*-Value
Age (years)	164	27.5	3.8	51	27.8	5.4	0.720
Height (cm)	164	178.7	6.5	51	178.4	8.5	0.809
Mass (kg)	164	85.7	9.1	51	83.8	11.8	0.229
Years of service	162	7.6	2.9	51	7.9	5.4	0.867

Anthropometrics

Average height from two measurements was taken barefoot using a wall stadiometer (Doran Scales, Inc, Batavia, IL, USA). Body mass (kg), fat free mass (FFM), and fat mass (FM) were estimated using Bod Pod (Bod Pod Body Composition System, Cosmed, Chicago, IL, USA). Fat mass index (FMI) and fat free mass index (FFMI) were calculated from fat mass and fat free mass Bod Pod measurements and height measurements (FMI = fat mass [kg]/height [m^2]; FFMI = fat free mass [kg]/height [m^2]). FMI and FFMI are height-normalized indices of body composition.[11] The Bod Pod was calibrated according to factory recommendations the day of each testing session.

Anaerobic Performance

Peak power (anaerobic power – AP) and mean power (anaerobic capacity – AC) were measured using a VeloTron cycling ergometer (RacerMate, Seattle, WA, USA) during a Wingate protocol. Seat and handlebar position were adjusted to ensure a comfortable position and 10° flexion of the knee during full extension. Following a 5-min warm up (125 W), subjects completed a 30-s Wingate protocol (9.0% body weight braking torque). Subjects were instructed to pedal as hard and as fast as they could against the applied resistance for the length of the test, all while maintaining a seated position and front handgrip position. Verbal encouragement was provided by the investigators. AP and average AC were analyzed in absolute units (W) as well as relative to body weight (W/kg).

Aerobic Capacity

Maximal oxygen uptake (VO_2max) was assessed using a metabolic gas analyzer (TrueOne 2400, ParvoMedics, Sandy, UT, USA) during a modified Astrand treadmill protocol to volitional exhaustion. The treadmill protocol was based on a variation of the protocol designed by Astrand.[12] Heart rate data were collected with a heart rate monitor (Polar USA, Lake Success, NY, USA) and blood lactate was assessed with a portable lactate analyzer (Lactate Pro, Arkray, Inc, Kyoto Japan). The speed for the test was selected according to the subject's most recent self-reported three mile run time, and incline was increased 2% every 3 min until volitional exhaustion.

Strength

Isokinetic strength of the knee and trunk was assessed using an isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY, USA). Knee extension/flexion strength and trunk extension/flexion strength were measured during a concentric/concentric protocol at 60°/s with submaximal and maximal practice repetitions. The test consisted of five maximal strength repetitions (100% max effort) with verbal encouragement from the investigators. Strength was determined by the average of five repetitions, and analyzed in absolute units (Nm) as well as relative to body weight (%BW).

Diet Assessment

A subgroup (CSOs = 27, enablers = 22) reported their dietary intake via the Automated Self-Administered 24-h (ASA24) dietary recall system on a computer. Before data collection, subjects were provided detailed instruction by investigators on how to complete the recall survey. Following familiarization, they completed the 24-h dietary recall survey during the laboratory testing session.

Statistical Analysis

Data were assessed for normality via histogram plots and Shapiro–Wilk tests. Independent samples *t*-tests were used for normally distributed data. Mann–Whitney *U* tests were used for data that were not normally distributed. Data are presented as mean ± standard deviation (SD). All physiological performance and absolute strength data were analyzed collectively and presented as percentage of CSOs and enablers in the 0–25th, 25–50th, 50–75th, and 75–100th percentiles. Fisher's exact tests were used to analyze the association between the percentage of CSOs and enablers in each percentile. Data were also analyzed and presented relative to a normal distribution curve. SPSS Statistics for Windows (SPSS Inc., Chicago, IL, USA) version 23 was used for all analyses. Significance was set at $p < 0.05$.

RESULTS

Laboratory Assessments

Descriptive data for both groups are presented in Table I. There were no significant differences for age, height, mass, or years of military service between CSOs and enablers ($p > 0.05$). Physiological and strength laboratory data relative to mass are presented in Table II. There were no significant differences in FM, FFM, and FMI ($p > 0.05$), however, CSOs had significantly greater FFMI than enablers ($p = 0.011$). CSOs demonstrated significantly greater physiological performance than enablers in AP (W/kg) ($p = 0.020$), AC (W/kg) ($p = 0.001$), VO_2max (ml/kg/min) ($p = 0.018$), and VO_2 (ml/kg/min) @LT ($p = 0.007$). There were no significant differences in VO_2max% @LT ($p > 0.05$). CSOs also demonstrated greater KF (%BW) ($p = 0.001$), KE (%BW) ($p = 0.001$), TE (%BW) ($p = 0.010$), and TF (%BW) ($p = 0.016$).

Physiological and absolute strength data are also presented in Table II. CSOs demonstrated significantly greater physiological performance than enablers in AC (W) ($p = 0.03$), VO_2max (l/min) ($p = 0.001$), and VO_2 (l/min) @LT ($p = 0.001$). There were no significant differences in AP (W) ($p > 0.05$). CSOs also demonstrated greater KF (Nm) ($p = 0.001$), KE (Nm) ($p = 0.001$), TE (Nm) ($p = 0.010$), and TF (Nm) ($p = 0.016$).

Percentile distribution of physiological performance and absolute strength of CSOs and enablers are presented in (Fig. 1). Fisher's exact tests showed that a statistically higher proportion of enablers performed in the 0–25th percentile of VO_2max ($p = 0.047$), AP ($p = 0.046$), and KF ($p = 0.006$) compared with CSOs. There were no statistically significant differences between enablers and CSO for all other percentile groups ($p > 0.05$). Finally, physiological performance and absolute strength data were analyzed relative to a normal distribution curve to highlight performance and strength distribution between CSOs and enablers (Figs 2 and 3).

Dietary Characteristics

The dietary intake of a subgroup of CSOs and enablers is outlined in Table III. No group differences were observed in absolute energy or macronutrient intake. No group differences were observed in carbohydrate and protein intake per kilogram body weight. Carbohydrate intake per kilogram body weight for both groups (3.1 g/kg) was consistent with recommendations for participating in low intensity or skill-based activities and below the recommendation of >5 g/kg to support optimal performance during moderate to high-intensity tasks.[13] Percent energy intake from fat was above the Dietary Reference Intake Acceptable Macronutrient Distribution Range (recommended 20–35% kcals from fat) in both groups.[14]

DISCUSSION

The present study examined the differences in physical, physiological, and dietary characteristics of MARSOC CSOs and enablers. CSOs were found to have a greater fat free mass index, peak and mean anaerobic power, maximal aerobic capacity, and greater leg and trunk strength compared with enablers. Physiological and strength percentile distribution among CSOs and enablers was highly variable, with a greater percentage of enablers occupying the 0–25th percentile for all measures. Inadequate carbohydrate intake and a higher than recommended intake of energy from fat were also identified in CSOs and enablers. These findings may directly relate to the operational capability of a MSOT, highlighting overall fueling concerns and raising important questions as to how physiological and strength characteristics among CSOs and enablers affect the tactical capability of an MSOT.

While we found no significant differences between key body composition variables that measure absolute fat mass and fat free mass, we did find that when these variables were normalized to height, CSOs have more lean mass and were leaner than enablers. These height-normalized indices suggest that CSOs tend to have more muscle mass for their body size, findings that may have a direct impact on strength to weight ratio and ultimately performance, especially when not required to carry a significant external load. Whereas some MSOT members may aim to gain absolute size and strength per se, both CSOs and enablers must move their own body mass, therefore it can be argued that it is just as important to optimize power to weight ratios rather than absolute power. As a part of their future training regimen, a focus on changing body composition to increase lean mass while reducing fat mass is likely to have a favorable effect on their power to weight ratio to ultimately improve performance.

Physiological and strength data in the present study showed CSOs to be comparable with other US Special Operations

TABLE II. Physiological and Strength Measures

	CSOs			Enablers			*p*-Value
	n	Mean	SD	*n*	Mean	SD	
Physiological							
Fat free mass (kg)	163	71.1	7.1	49	68.8	9.4	0.067
Fat mass (kg)	163	14.7	5.0	49	15.3	6.2	0.474
Fat free mass index	163	22.2	1.6	49	21.5	1.8	0.011*
Fat mass index	163	4.6	1.5	49	4.8	1.9	0.474
Anaerobic power (W/kg)	162	13.0	0.6	46	12.7	0.8	0.020*
Anaerobic power (W)	162	1121.4	150.7	46	1089.3	190.6	0.232
Anaerobic capacity (W/kg)	162	9.1	0.8	46	8.5	1.0	0.001*
Anaerobic capacity (W)	162	785.1	94.4	46	731.2	134.1	0.003*
VO_2max (ml/kg/min)	134	49.6	4.5	46	47.7	4.4	0.018*
VO_2max (l/min)	134	4.1	0.4	46	3.9	0.5	0.001*
VO_2max% @LT	134	90.3	3.9	46	89.7	4.4	0.350
VO_2 (ml/kg/min) @LT	134	44.7	3.9	46	42.8	4.5	0.007*
VO_2 (l/min) @LT	134	3.8	0.3	46	3.5	0.5	0.001*
Strength							
Knee flexion (%BW)	154	140.9	23.0	43	125.4	25.8	0.001*
Knee flexion (Nm)	154	121.0	23.8	43	105.0	25.2	0.001*
Knee extension (%BW)	155	266.8	45.8	43	239.1	53.4	0.001*
Knee extension (Nm)	155	229.0	46.9	43	201.3	53.4	0.001*
Trunk extension (%BW)	152	407.8	77.5	43	374.6	65.6	0.010*
Trunk extension (Nm)	152	348.9	76.7	43	313.9	65.5	0.018*
Trunk flexion (%BW)	153	242.1	39.6	43	224.9	48.8	0.016*
Trunk flexion (Nm)	153	207.5	41.0	43	190.0	52.3	0.034*

*Significant difference between personnel $P < 0.05$.

kg, kilograms; W, watts; ml/kg/min, milliliters oxygen per kilogram of body weight per minute; %BW, percentage of body weight in kilograms; Nm, newton meters; LT, lactate inflection; VO_2max%, percentage of VO_2max (ml/kg/min).

Operators.[15–17] CSOs demonstrated significantly higher overall maximal aerobic capacity and aerobic capacity at lactate threshold than enablers, an essential attribute for combat centric military occupations with many common tactical tasks requiring longer durations of moderate intensity physical activity. Individuals with higher aerobic fitness perform endurance activities at a lower fraction of their maximal aerobic capacity, for longer periods of time, fatigue less rapidly, and are at decreased risk for injury development.[8,18–21] Moreover, CSOs also demonstrated significantly greater strength, peak and mean power, which are also important performance components that are often used in tactical situations that require high force and quick, explosive movements.[6] Compared to CSOs, enablers present a greater likelihood of not meeting the strength and anaerobic demands of operational tasks, resulting in greater physiological strain and subsequently increasing risk of musculoskeletal injury.[6,22]

Specific military tasks, such as rucking or carriage loads over lengthy distance, may present critical issues for enablers, who demonstrated significantly lower aerobic capacity, power and strength than CSOs. Rucking stresses both aerobic and anaerobic pathways and places a heavy demand on the spine, lower back, and knees.[7,23,24] Musculoskeletal injuries, specifically low back (pain/injuries), are a top contributor to loss of duty days on deployment and are directly related to fatigue and the mismatching of strength capability and strength demands.[25] Enablers demonstrated that they are more likely to fatigue faster, and in conjunction with reduced lower extremity and trunk strength, operational tasks such as rucking may present a much higher risk of musculoskeletal injury.

Given the significant performance differences between CSOs and enablers, further consideration should also address the distribution of performance between CSOs and enablers and the potential negative implications it may present on a MSOT. Overall, a greater percentage of enablers occupied the 0–25th percentile of all laboratory measures, with a statistically significant percentage of enablers in the 0–25th percentile for VO_2max ($p = 0.047$), AP ($p = 0.046$), and KF ($p = 0.006$) (Fig. 1). The disparate range of performance between the groups is also emphasized when analyzed to a normal distribution curve (Figs 2 and 3). This uneven distribution increases the likelihood of an enabler in the lower range of performance to be paired with CSOs in the higher range of performance, potentially resulting in an unbalanced physical readiness profile of a MSOT. Tactically, this may result in higher performers taking on more tasks to make up for the weaker performers, potentially reducing the overall capability of the team. However, these novel findings still do not provide definitive data on the exact impact of mission oriented performance, but do raise important questions about what standards are necessary to operate effectively as a member of a MSOT.

At this time, specific physiological and strength thresholds to successfully operate in a SOF environment do not exist, so it is

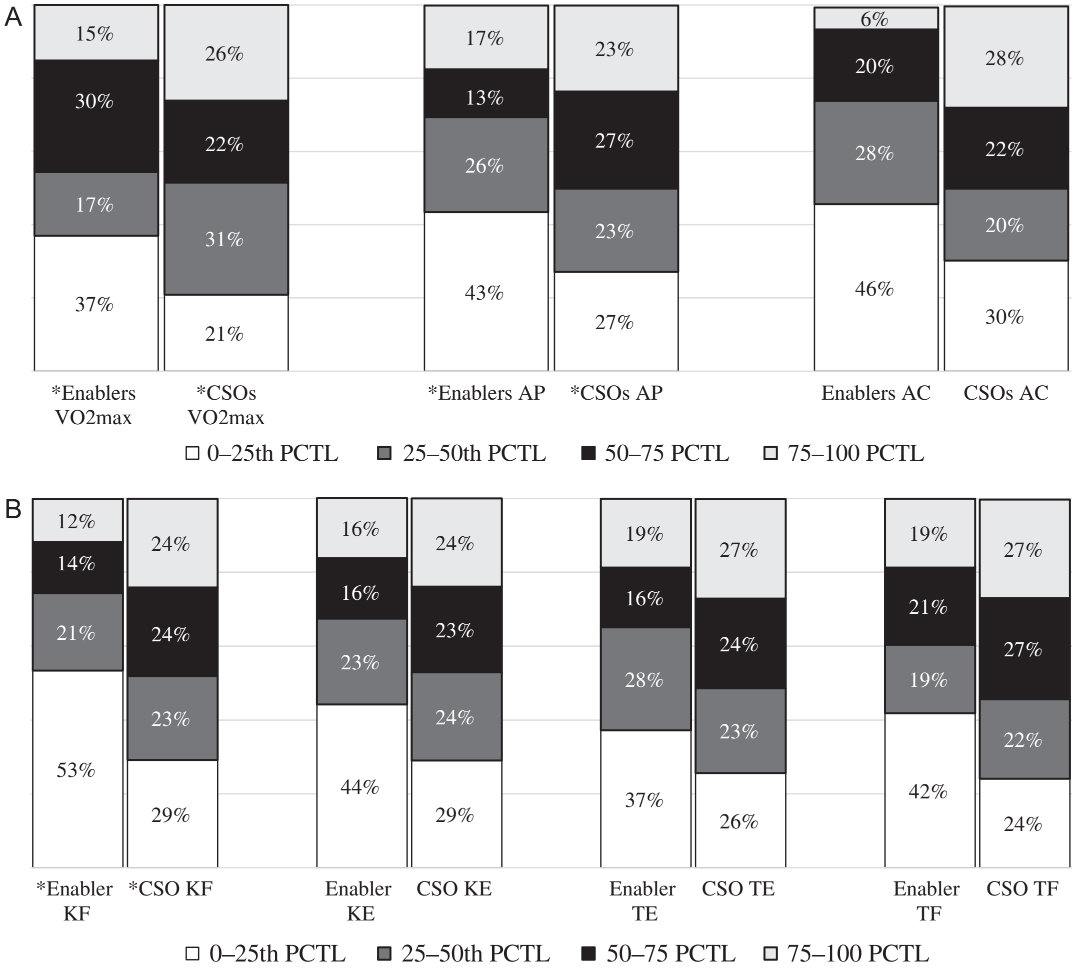

FIGURE 1. (A) Physiological percentile distribution and (B) strength percentile distribution.

beyond the scope of this study to say whether or not enablers can effectively operate as members of a MSOT. Future research should focus on the development of a needs analysis to determine what performance thresholds and occupational requirements are essential to operate effectively as a member of a MSOT. This will help determine if the significant differences in performance represent a true physical readiness gap and whether or not the implementation of additional functional training to improve overall performance is necessary. Performance thresholds would also provide important information that could help better guide the selection process for both CSOs and enablers.

Given the suboptimal macronutrient intake characteristics identified in CSOs and enablers, significant nutritional modifications are required to improve body composition and address fueling requirements to support a rigorous physical training program. Absolute carbohydrate intake lower and fat intake as a percentage of energy intake exceeded the Acceptable Macronutrient Distribution Range recommendations. Inadequate carbohydrate intake has the potential to reduce the adaptations to training by limiting performance and recovery, as well as contributing to a state of chronic fatigue. Excess fat intake may negatively affect diet quality by displacing carbohydrate other nutrient-dense food and in turn decrease performance and increase the risk of injury. Access to, and utilization of MARSOC nutrition specialists to promote these nutritional modifications should be a point of emphasis for enablers and CSOs. Personalized nutrition support and education should extend beyond daily recommendation to also provide evidence based strategies to support acute fueling needs that encompass all aspects of training and deployment. These strategies, in conjunction with the utilization of MARSOC performance experts, may ultimately help bridge the performance gap between CSO's and enablers.

CONCLUSION

MARSOC CSOs demonstrated significantly greater fat free mass index, power, endurance, lower extremity, and core strength compared with enablers, while nutrition fueling concerns were identified for both CSOs and enablers. Performance differences may be directly related to the rigorous selection process and training of a CSO when compared to that of an enabler. Currently, specific physiological and strength thresholds to successfully operate in a SOF environment do not

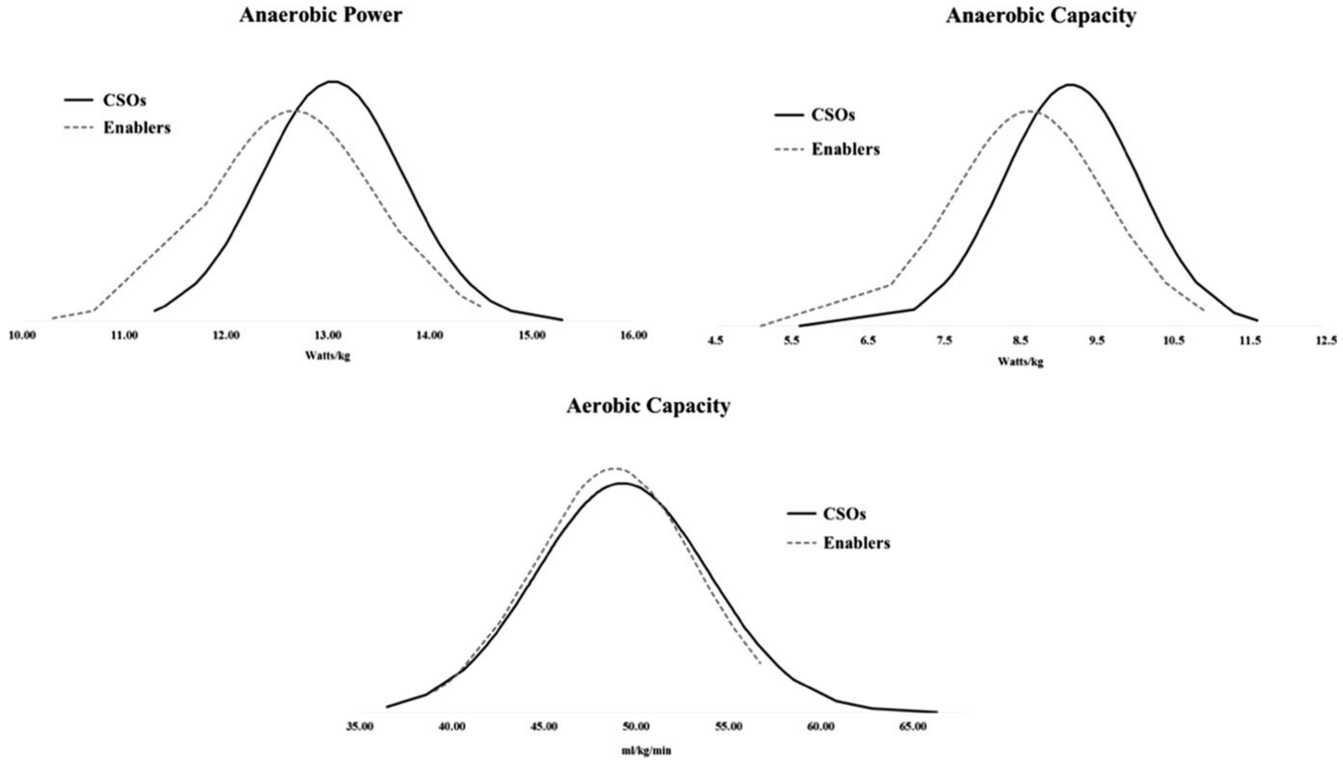

FIGURE 2. Physiological performance normal distribution curves.

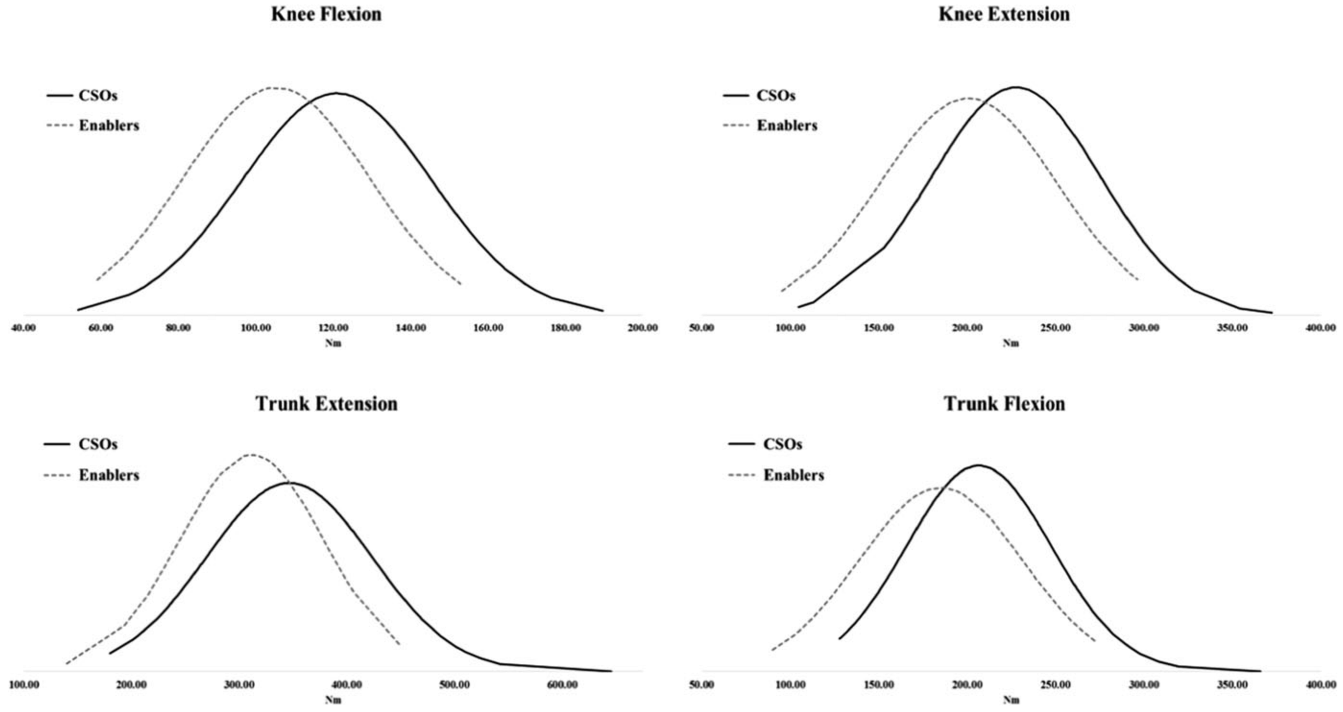

FIGURE 3. Absolute strength normal distribution curves.

exist, so it is beyond the scope of this study to say whether or not enablers can effectively operate as members of a MSOT.

Future research should aim to develop a needs analysis to determine what physiological thresholds are required to effectively operate as a member of a MSOT and the validity of these measures with respect to mission-specific capabilities. Such findings may provide meaningful information that may better guide MARSOC selection processes, while also

TABLE III. Dietary Intake

	CSOs			Enablers		
	n	Mean	SD	*n*	Mean	SD
Kilocalories	27	2752	1073	22	2555	856.1
Carbohydrate (grams)	27	272.7	145.8	22	247.4	96.8
Carbohydrate (grams/kg)	26	3.1	1.7	21	3.1	1.3
Protein (grams)	27	154.7	98.9	22	127.6	62.1
Protein (grams/kg)	26	1.8	1.2	21	1.5	0.8
Fat (grams)	27	112.1	50.6	22	115.7	53.5
Fat (% energy)	27	36	7.5	22	39.5	8.2

potentially leading to implementation of specific and directed training, for both CSOs and enablers. Lastly, creating a clearer performance standard for all members of a MSOT may subsequently lead to increased tactical performance and decreased injury incidence rates.

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Altered Physical Performance Following Advanced Special Operations Tactical Training

Abstract:

The purpose of this study was to determine how the unique challenges of specific military tactical training phases influence overall physical performance characteristics. Broad jump, 5-10-5, 300 yard shuttle, percent body fat (%BF), anaerobic power (AP) and capacity (AC), maximal oxygen uptake (VO_2max), isokinetic knee extension/flexion strength, shoulder internal/external rotation strength, trunk extension/flexion strength, were collected on 73 United States Marine Corps Forces Special Operations Command (MARSOC) students (Age: 27.4 ± 3.8 years, Height: 178.7 ± 6.6 cm, Mass: 85.8 ± 9.4 kg) at the beginning of (P1), in between (P2), and at the completion of two distinct tactical training phases (P3). Linear mixed models were used to analyze within-subject performance changes over the three time points and post-hoc Bonferroni pairwise comparisons analyzed performance changes between each testing time point. There were significant changes in broad jump ($p<0.0001$), 5-10-5 agility time ($p<0.001$), %BF ($p=0.011$), AP ($p<0.0001$), VO_{2max} ($p=0.001$), and both right and left shoulder internal rotation strength ($p=0.004$ and $p=0.015$ respectively) between P1 and P2. There were also significant changes in 300-yd shuttle run time ($p=0.001$), AP ($p<0.0001$), AC ($p<0.0001$), left knee extension strength ($p=0.006$), trunk flexion strength ($p<0.0001$), and left shoulder external rotation strength (0.027) between P2 and P3. Identifying the affect that specific tactical training phases may have on physical performance will allow for the development of effective phase specific evidence-based human performance programs, reducing performance deficits and thereby reducing the risk of injury.

Keywords:

Military, physical performance, injury prevention, performance optimization

INTRODUCTION:

The United States Special Operations Forces (SOF) conduct a wide range of specialized missions stressing both neuromuscular and physiological aspects of human performance. Due to the rigorous physical stress under extreme military training environments, SOF personnel are at an increased risk of sustaining a musculoskeletal injury, with approximately 20.8% of SOF personnel reporting a musculoskeletal injury occurring within the previous year (1). Suboptimal levels of performance may negatively affect tactical capabilities and increase the risk of sustaining a musculoskeletal injury (6, 24, 25). Performance characteristics such as aerobic fitness are often stressed during tactical training and reduced levels have been associated with an increased risk of injury (6, 7, 12, 17, 37). This is likely due to the fact that many tactical tasks require long-term, moderate intensity physical activity. Additionally, strength and power are both critical requirements necessary for tactical training and suboptimal levels of either strength or power have been associated with lower extremity injuries including overuse injuries at the knee (23, 26). Load carriage during rucking, which is an essential component of SOF training, places a heavy demand on the spine, lower back and knees. (18, 31, 32) Sufficient levels of lower extremity and trunk strength are needed during rucking for stabilization and postural control and decreased levels of strength have been associated with musculoskeletal injuries during load carriage (6, 33). High levels of overall physical performance are critical for the prevention of injuries and the ability to effectively operate in a continuous tactical training environment such as that of SOF. Before we can improve physical training to mitigate the effects of specific tactical training phases, we must understand how such training can affect important physiological and musculoskeletal characteristics.

Tactical training is physically demanding, requiring high levels of physical performance including strength, power, and aerobic fitness. During physically intense tactical training phases such as basic combat training, overuse injures account for approximately 75% of all injures. These overuse injuries include pain, sprains, and strains and are commonly reported in the lower extremities and low back (18). Due to the rigorous physical stress under extreme military environments, SOF personnel continuously participate in physical training programs in order to optimize performance and reduce injury during combat. Interestingly, of the 20.8% of SOF personnel reporting a musculoskeletal injury within the previous year, 76.9% of these musculoskeletal injuries were classified as preventable (1). Preventable injuries often occur during physical training, with running and lifting being reported as a common cause of these injuries (9). These results indicate the need for the development of safe, yet effective, physical performance training programs. Understanding the changes in performance that occur during specific phases of tactical training will further optimize physical training programs, by identifying aspects of performance that need to be addressed in order to optimize preparation for and recovery from different SOF tactical training phases. Evidence-based physical performance programs that are focused on addressing the necessary aspects of performance are critical for SOF personnel to maintain sufficient levels of operational readiness and improving overall resiliency.

Prior to becoming a Marine Raider with Marine Corps Forces Special Operations Command (MARSOC), Marines must successfully complete an intensive Assessment and Selection process and Marine Raider Training Center's (MRTC) Individualized Training Course (ITC). ITC consists of five distinct tactical training phases over a nine-month period designed to push the individual physically and mentally, training the Marine in a multitude of tactical skills that are required during SOF operational missions. These phases include: survival, evasion, resistance, escape (SERE) training, ground combat and amphibious operations training, special reconnaissance, direct action training (marksmanship and close quarter battle), and irregular warfare (3). Following the successful completion of ITC, officers, now considered Special Operations Officers (SOOs), transfer to their assigned battalion while the enlisted operators, now considered Critical Skills Operators (CSOs), remain at the MRTC and complete a 6-month basic language course (BLC) (3). BLC places additional mental and physical stress on the CSO, by requiring them to complete an intense foreign language course while also completing a Special Operations Combatives program (SOCP). Though BLC places additional stress on the CSO, it utilizes a regimented schedule which provides an opportunity for the CSO to incorporate physical performance training programs and recovery strategies in preparation for subsequent pre-deployment individual and unit-based training at their assigned battalion. Because of the high incidence of musculoskeletal injuries associated with the tactical training environment of SOF identifying the physical performance changes specific to ITC, and/or BLC is needed prior to the development of effective performance training programs focused on preparation for an upcoming tactical training phase, performance maintenance during a current tactical training phase, and/or adequate physical recovery from a previous tactical training phase.

MRTC is a critical component of MARSOC and becoming a Marine Raider requires the successful completion of the rigorous tactical training during ITC that is often repetitive and physically demanding, placing the Marine at an increased risk of injury. In general, there is a lack of understanding of how physiological and musculoskeletal performance is affected by the rigorous, both physical and mental, tactical training involved in ITC and the additional stressors associated with BLC. In order to develop effective MARSOC specific performance training programs and injury prevention strategies, we must first identify exactly how ITC and BLC, as they currently exist, impact physical and physiological performance. Therefore, the purpose of this study was to follow a training class through each of the MRTC training phases and determine how specific performance characteristics are influenced by the physical rigors of ITC and identify if Marines are adequately recovering and improving these performance characteristics during BLC. We hypothesize that physical performance will decrease from the beginning (pre-ITC) to end of ITC (post-ITC) and improve from the beginning (post-ITC) to end of BLC (post-BLC).

METHODS:

Experimental Approach to the Problem:

This study was a longitudinal analysis designed to examine changes in physical characteristics and performance across the different MRTC's training phases, testing a class of Marine Raider students at three distinct times points **(Figure 1)**: The beginning of ITC (P1), the end of ITC but before BLC (P2), and the end of BLC (P3). Marines completed one field testing session including broad jump, 5-10-5 agility test, deadlift, and 300-yard shuttle test. On a separate day, Marines completed one laboratory testing session lasting approximately three hours at each time period. Laboratory sessions included: physiological and muscular strength testing.

Subjects:

A total of 73 ITC students (Age: 27.4 ± 3.8 years, Height: 178.7 ± 6.6 cm, Mass: 85.8 ± 9.4 kg, and 8.3 ± 3.2 years of service) were recruited from MARSOC. Inclusion criteria included MARSOC membership, cleared for full and unrestricted participation in physical and tactical training, and free of musculoskeletal injury within the past month that led to training cessation or medical treatment. Subjects were also asked to limit any strenuous physical training, avoid caffeine, nicotine, and alcoholic beverages twenty-four hours prior to testing. All research procedures obtained approval from the University's Institutional Review Board. Written informed consent was obtained from each subject prior to participation in the study.

Procedures:

Body Composition: Average height (cm) from two measurements was taken barefoot using a wall stadiometer (Doran Scales, Inc, Batavia, IL). Body mass (kg) and body composition were estimated using Bod Pod (Bod Pod® Body Composition System, Cosmed, Chicago, IL). Unfavorable body composition (increased percent body fat) has shown to be associated with an increased risk of injury within military personnel (11, 31). Additionally, less body fat is associated with better aerobic and anaerobic capacity, suggesting the importance of this variable for overall performance (4). For body composition testing, a standard protocol was performed according to the manufacturer's recommendations. Subjects wore spandex shorts and a swim cap. Once two consistent body volume measurements were obtained, percent body fat (%BF) was calculated using predicted lung volume and the appropriate body densitometry equation. Body composition assessments using this protocol in similar environments have demonstrated to be reliable (intraclass correlation coefficient (ICC): 0.98) and precise (standard error of measurement (SEM): 0.47% BF) (4).

Anaerobic Performance: Anaerobic testing was performed on a VeloTron magnetically-braked cycle ergometer (RacerMate, Seattle, WA) (34). Subjects completed a 5-minute warm up (125W) at a self-selected cadence. Following the warm-up, participants completed a 30-second maximal test in which they were instructed to pedal as hard and as fast as possible throughout the entire duration of the test, whilst maintaining a seated position and holding the top of the handlebars. Following three seconds to increase cadence as quickly as possible, a 9.0% body weight braking torque was immediately applied and maintained for the remaining 30 seconds. Peak anaerobic power was calculated as the peak power during the test. Anaerobic capacity was calculated as the mean power throughout the 30 seconds. Peak anaerobic power and mean anaerobic capacity are reported relative to body weight (W/kg).

Aerobic Performance: Maximal oxygen uptake (VO_2max) was assessed using a metabolic gas analyzer (TrueOne 2400, ParvoMedics, Sandy, UT) during a modified Astrand treadmill protocol to volitional exhaustion. The treadmill protocol was based on a variation of the protocol designed by Astrand (13). The speed for the test was selected according to the subject's most recent self-reported three-mile run time. This speed remained constant during the test, and incline was increased 2% every three minutes until volitional exhaustion. Heart rate data were collected with a heart rate monitor (Polar USA, Lake Success, NY). Blood lactate levels were collected via finger stick (Lactate Pro, Arkray Inc, Kyoto, Japan) at rest, at the end of each test stage, immediately upon test termination, and 3 minutes after test completion. Lactate threshold was identified as the inflection point where blood lactate increased nonlinearly during the testing protocol and was reported in relation to the value of oxygen consumption (VO_2) at that timepoint. Data was analyzed relative to body mass (ml/kg/min).

Strength: Isokinetic strength of the knee, shoulder, and trunk were assessed using an isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY). Knee extension/flexion strength, shoulder internal/external rotation strength, and trunk extension/flexion strength were measured during a standard concentric/concentric protocol at 60°/sec with submaximal and maximal practice repetitions (30, 34) . The deficits in those strength characteristics have been associated with individuals with musculoskeletal injuries and altered movement control (2, 10, 19, 23, 27). Trunk flexion and extension strength assessment previously have been found to be reliable using similar methodology and instrumentation (5, 14) (ICC: 0.74-0.98). Each strength test consisted of five maximal repetitions (100% max effort) with verbal encouragement from the investigators. Strength was determined by the average of 5 repetitions and analyzed relative to body weight (%BW) and in absolute terms (Newton meters (Nm)).

Field Measures: For broad jump testing, each participant completed three maximal jumps on a flat surface and were instructed to “stick” the landing. The distance jumped was measured as the distance from the toes at the start, to the heel closest to the start during the landing. The farthest jump of the three trials was recorded. The 5-10-5 shuttle test was conducted using a standard protocol (36). The test was performed once breaking to the right, and once breaking to the left. The average of the two trials was used for the analysis. The 300-yard shuttle test was a maximal test consisting of 6 x 50-yard shuttles (25 yards in each direction). Each participant completed the assessment in the fastest time possible, making sure that at least one foot was on or over the line at each end, during each shuttle. Following a break of 2 minutes the test was repeated. The average of the two times were used for analysis. The filed measures were assessed on a separate day by MARSOC human performance personnel.

Statistical Analyses:

Linear mixed models were used to analyze within-subject performance changes over the entire course of the MRTC training pipeline. The MRTC is a complex training environment with limited availability for the Marines to complete testing at any given timepoint and is also associated with high failure and/or dropout rates. Therefore, linear mixed models were chosen for this analysis to avoid the listwise deletion of subjects from the entire analysis who did not have complete data sets. Linear mixed models have been used previously to avoid listwise deletion in clinical trials with multiple follow-up timepoints (39). Post-hoc pairwise comparisons were performed to analyze phase specific differences with MRTC using Bonferroni corrections to protect against a Type I statistical error. Effect size estimates using partial eta squares were calculated from the unbalanced mixed model analyses for variables with a significant effect of time. Normality was assessed using Shapiro-Wilk tests. Significance was set *a priori* at $p \leq 0.05$. All statistical analyses were performed using IBM SPSS 23.0 (IBM Corp, Armonk, NY) statistical software.

RESULTS:

According to the results from the linear mixed models **(Tables 1-3)**, there were significant changes in multiple physical performance characteristics among the three testing time points (P1, P2, and P3) during the MRTC training pipeline. Post-Hoc Bonferroni pairwise comparisons

(Tables 1-3) revealed the significant changes in physical performance characteristics specific to each tactical training phase (P1 to P2, P2 to P3, and P1 to P3).

P1 to P2

Post-Hoc Bonferroni pairwise comparisons revealed significant decreases in %BF ($p=0.011$), AP ($p<0.001$), VO_{2max} ($p=0.001$), and the $VO2_{LT}$ ($p =0.037$) while the lean mass was significantly increased at P2 ($p<0.001$). Contrary to physiological changes, there were few significant differences in muscular strength between P1 and P2. Right and left shoulder internal rotation strength was significantly increased at P2 ($p=0.004$ and $p=0.015$ respectively). For field testing, broad jump ($p<0.001$) was significantly increased at P2 while 5-10-5 agility time was significantly decreased ($p<0.001$).

P2 to P3

Post-Hoc Bonferroni pairwise comparisons comparing performance changes during BLC revealed significant increases in lean mass ($p=0.027$), AP ($p<0.001$), AC ($p<0.001$), left knee extension strength ($p=0.006$), and trunk flexion strength ($p<0.0001$). Interestingly, there was a decrease in left shoulder external rotation strength (0.027) and the 300-yd shuttle run time increased during BLC ($p=0.001$).

P1 to P3

While phase specific changes were observe between either P1 and P2 or P2 and P3 the post-hoc Bonferroni pairwise comparisons also revealed a significant increase in lean mass ($p<0.001$), AP ($p<0.001$), trunk extension strength ($p=0.012$), trunk flexion strength ($p<0.001$), broad jump ($p<0.001$), and 300-yd shuttle run time ($p<0.001$) over the course of the entire MRTC (P1 and

P3). There was also a significant decrease in %BF ($p=0.013$), VO_{2max} ($p<0.001$), and 5-10-5 agility time ($p<0.001$). The decrease in 5-10-5 agility time is an increase in performance. Though these significant differences are not phase specific, it is specific to the MRTC, demonstrating gradual improvement throughout the entire MRTC pipeline.

DISCUSSION:

The MRTC training pipeline is an extensive tactical training pipeline designed to instruct and assess the Marine on the critical skills needed to effectively operate as a SOF Marine Raider. These training pipelines require that the Marine function in environments that replicate the physical and mental stressors experienced during SOF deployment to a variety of military theaters but may negatively impact some characteristics of physical performance. The purpose of this study was to determine how specific performance characteristics were influenced by the physical rigors of ITC and may or may not recover during BLC. The results for this study revealed that the physical stress experienced by the Marine during ITC significantly decreased their %BF, AC, VO_{2max}, $VO2_{LT}$, and agility (5-10-5). These findings highlight the types of physiological stressors placed on the individual during ITC and could be considered areas of focus for physical performance training recommendations for Marines preparing for ITC. Though the actual decrease in these performance characteristics during ITC are not very large, for example VO_{2max} is 2 ml/kg/min with ~25% of the variability accounted for by time ($\eta^2_p=0.252$), any decrement in performance is significant to a Marine Raider. Small decreases in aerobic capacity, anaerobic capacity, and agility may be life threatening in a combat situation. Identifying potential performance deficits regardless of the magnitude of the deficit, is impactful as Marine Raiders need to maintain high levels of performance at all times.

Though the tactical training during ITC is physically demanding with limited time for recovery, not all of the performance changes were negative; lean mass and shoulder internal rotation strength significantly increased as did the broad jump. Although BLC did show increases in lean mass, certain strength characteristics, and both AP and AC **(Figure 2)** other aspects of performance such as VO_{2max} **(Figure 3)** did not recover. In fact, the 300-yard shuttle run, the field assessment for aerobic capacity, slowed over BLC. These findings suggest a lack of aerobic conditioning during BLC and should guide physical training, improving the performance characteristics that were depleted during ITC while maintaining the improved levels of the other performance characteristics.

BLC consists of a regimented class structure providing the Marine Raider with an opportunity to physically recover from ITC and begin preparation for pre-deployment unit training. Based on the results from this study, the current physical training environment during BLC is successful at improving AP, knee extension strength symmetry (by improving the weaker limb's knee extension strength), core trunk flexion strength, low back trunk extension strength, and agility (5-10-5 shuttle). The strength and power aspects of human performance are extremely important for the SOF Operator, improving tactical performance during deployments as well as overall resiliency (6, 28). Improved core and low back strength **(Figure 4)** along with knee extension strength symmetry is necessary to more effectively absorb and control the heavy demands often placed on the spine, lower back and knees during training exercises such as rucking.(18, 31, 32) Along with low-back injuries, lower extremity injures, specifically at the knee, are extremely prevalent in the military and improved knee extension strength symmetry may also reduce the risk of sustaining such an injury (29). Though increases in trunk strength are often beneficial, significant asymmetrical increases in trunk flexion compared to trunk extension may not be ideal. During BLC trunk flexion increased by approximately 34 %BW (η^2_p=0.286), while trunk extension increased by only 8 %BW (η^2_p=0.105). This disproportional increase in trunk flexion, compared to trunk extension may indicate an emphasis on core strengthening during BLC. This is likely due to the fact that utilization of MARSOC specific performance training programs during BLC was inconsistent and the CSO adopted their own physical training program. Overall, the fact that 5-10-5 agility shuttle improved along with laboratory measures of strength and power further demonstrates the overall improvements in strength, explosiveness, and muscle coordination during BLC.

During BLC physical training programs are currently being developed by the human performance professionals at MARSOC incorporating functional strength, power, speed and agility, endurance, and movement quality, but utilization of these programs during BLC has been inconsistent and at the discretion of the CSOs. Though the current training environment during BLC effectively improves AP, AC, trunk flexion and trunk extension strength, certain performance deficits persist following ITC, such as $VO2_{max}$, and additional deficits develop including the 300-yard shuttle run and decreased shoulder external rotation strength. These performance deficits highlight possible gaps in the current physical training environment during BLC. Rucking and running over significant distances are core components of SOF training and military training in general, and deficits in $VO2_{max}$ may have significant impact on risk of injury during such tasks. Improving $VO2_{max}$ will prolong operational capability, decreasing fatigue which would significantly reduce the risk of musculoskeletal injuries (15).

Shoulder injuries are also a significant issue in the military, accounting for approximately 8-24%, of the musculoskeletal injuries.(8, 16, 21, 22) and having a high prevalence rate among SOF operators (9). Shoulder external rotation strength, which is critical for joint stabilization and the prevention of overuse musculoskeletal injuries (19), actually decreased during BLC. This is important as significant reductions in both shoulder internal and external rotation strength have been reported among individuals with a shoulder impingement (19). Again, this may be due to the fact that utilization of MARSOC specific performance training programs during BLC was inconsistent. Current MARSOC performance training programs often incorporate shoulder rotation strengthen exercises into their programs as accessory movements. Though the current BLC training environment successfully improves critical performance characteristics, certain performance deficits persist such as aerobic capacity and overall shoulder strength (both internal and external rotation. Strategies to improve MASORC performance training utilization or that incorporate training exercises addressing aerobic capacity and shoulder strength into the CSOs physical training program during BLC need to be developed to further improve physical performance and improve overall tactical readiness and resiliency.

Using the results from this study, current MARSOC MRTC human performance training programs can be modified to better accommodate the MRTC phase specific performance deficits that occur during their tactical training pipelines. Program modifications safely incorporating aerobic capacity and shoulder strength into current program design may effectively improve program gaps without interfering with the current program effectiveness of improving core strength and peak anaerobic power. Incorporating aerobic training components may also provide additional recovery time for the more commonly trained performance aspects, such as resistance training, that are more susceptible to overtraining and overuse injuries. Though aerobic training may provide much needed recovery time from resistance training, running had been reported as a common mechanism for injuries within MARSOC (9). Incorporating exercises such as high intensity interval training may improve VO_{2max}, $VO2_{LT}$, AC while reducing the overall volume of loading to the lower extremities and spine.

MRTC is a critical component of MARSOC designed to prepare and evaluate the Marine's ability to operate in a SOF environment and the successful completion of the MRTC pipelines are required to become a Marine Raider. While there have been previous studies examining the physical effects of deployment, (20, 24, 35, 38) this longitudinal study is the first to examine the physical effects of the MARSOC MRTC training pipelines. Several studies examining the physical effects of deployment have reported decreased aerobic capacity, body fat %, shoulder strength/flexibility, static balance, and increased musculoskeletal injuries (20, 24, 35, 38). These longitudinal studies serve as a rough estimate of physical and mental stress experienced by the solider and provide the guidance on how military individuals should prepare for their deployment. Identifying MRTC phase specific deficits during the intense tactical training pipeline will better inform human performance professionals as to what modifications to the current performance training environment are needed to refine MRTC preparation, improving completion rates and reducing injury during ITC, while promoting physiological recovery and preparation for the deployment training following BLC.

There were a few limitations to this study. The physical performance training environment during BLC was inconsistent, as performance training was at the discretion of the Marine Raider.

The intent of this study was to examine the MRTC phase specific performance changes in its current environment in order to develop effective modifications and/or recommendations specific to current MARSOC physical performance programs including improved utilization. Due to the difficult military research environment there was no control group, therefore the purpose of this study was to examine within-subject changes over the training phases of MRTC. This study only focused on one specific ITC class so that the tactical training requirements were similar between subjects and additional variability for other outside factors was minimized. Because access to subjects participating in military research is extremely difficult and this study only included Marines from one ITC class, linear mixed models were used for the repeated measures analyses in order to avoid listwise deletion.

Because the majority of preventable musculoskeletal injuries occur during physical training, approximately 60% (1), it is important to monitor and control the performance training environment. MARSOC provides human performance training programs with the guidance and direction of qualified professional personnel but utilization of these programs is sporadic, and access often depends on the Marine Raider's current tactical training pipeline. MARSOC human performance program modifications may need to initially focus on improving Marine Raider utilization in order to more accurately identify the necessary modifications that are needed to the programs as they currently exist.

The results for this study revealed significant phase specific changes in overall physical performance during ITC including decreases in %BF, AC, VO_{2max}, and the $VO2_{LT}$. Performance training programs designed specifically for the preparation of ITC should emphasize proper nutrition to help maintain body composition and improving both anaerobic and aerobic capacities while maintaining adequate levels of strength. Improving the performance characteristics most affected during ITC, in this case %BF, AC, VO_{2max}, and the $VO2_{LT}$, will likely improve ITC completion rates while reducing the performance deficits following ITC allowing for the Operator to begin the next phase of training at a higher level of performance. The current performance training environment during BLC is successful at improving critical aspects of strength and power (AP, knee extension strength symmetry, core strength, and 5-10-5 agility shuttle). While the current training environment during BLC improves certain characteristics of strength and power, other performance characteristics including aerobic capacity and shoulder strength remain depleted. Incorporating exercises that focus on improving aerobic capacity and shoulder strength into the current training environment will more effectively address the performance deficits associated with ITC, improving recovery and preparation for deployment training following BLC.

PRACTICAL APPLICATIONS:

In the SOF environment, small decrements in physical performance may be life threatening during combat situations. Based on the changes and trends in physical performance characteristics identified in this study, the development of performance training programs designed specifically for the preparation of ITC should emphasize improving both anaerobic and aerobic capacities while maintaining adequate levels of strength and proper nutrition to help maintain body composition. Incorporating training concepts such as high intensity interval training into programs designed specifically for ITC preparation may significantly improve both anaerobic and aerobic capacities while minimizing the burden of training time for the Marine.

Incorporating these types of exercises into current training programs should be done by a performance specialist, who understand training load and volume, to maximize the potential benefit and minimize the risk of injury. Though the current performance training environment during BLC is successful at improving critical aspects of strength and power, MARSOC performance training program utilization during BLC was very inconsistent. Incorporating exercises that focus on improving aerobic capacity such as interval training, and shoulder rotator cuff strength such as internal and external rotation with an elastic band, into the current training environment will more effectively address the performance deficits following ITC. Though similar exercises may already be incorporated into MARSOC sponsored training programs, performance deficits persist throughout BLC in its current state. Identifying performance changes over specific time points will allow for the development of effective evidence-based human performance programs. Though the information reported in this study is MARSOC-specific and military relevant, the concepts of evidence-based program design presented in this study are directly translational to a variety of performance training environments including all levels of athletics, rehabilitation, and first responders.

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FIGURES LEGEND:

1. MARINE RAIDER TRAINING CENTER TRAINING PHASES
2. ANAEROBIC POWER AND ANAEROBIC CAPACITY
3. AEROBIC CAPACITY
4. TRUNK STRENGTH

TABLE 1. PHYSIOLOGICAL CHARACTARISITCS

Physiology Variables	Linear Mixed Model Comparisons			P – Value	Effect Size (η^2_p)	Phase Specific Comparisons		
	P1 (n)	P2 (n)	P3 (n)			P1 – P2	P2 – P3	P1 – P3
Body Fat (%)	16.4 ± 4.8 (58)	15.4 ± 4.5 (54)	15.3 ± 4.3 (40)	0.003*	0.119	0.011	------	0.013
Lean Mass (lbs)	155.0 ± 13.9 (58)	158.6 ± 15.3 (54)	160.8 ± 13.8 (40)	<0.001*	0.403	<0.001	0.027	<0.001
Anaerobic Power (w/kg)	12.9 ± 0.6 (58)	13.0 ± 0.6 (53)	13.3 ± 0.7 (37)	<0.001*	0.286	------	<0.001	<0.001
Anaerobic Capacity (w/kg)	9.4 ± 0.8 (58)	9.1 ± 0.8 (53)	9.3 ± 0.8 (37)	<0.001*	0.223	<0.001	<0.001	------
Aerobic Capacity (ml/kg/min)	51.6 ± 4.5 (49)	49.6 ± 3.7 (45)	49.5 ± 3.6 (28)	<0.001*	0.252	0.001	------	<0.001
VO2 at Lactate Threshold	42.3 ± 3.3 (48)	40.9 ± 2.8 (45)	41.9 ± 3.0 (28)	0.042*	0.090	0.037	------	------

Mean, standard deviation, and number of subjects reported for each phase

TABLE 2. STRENGTH CHARACTARISITCS

Strength Variables (%BW)	Linear Mixed Model Comparisons			P – Value	Effect Size (η^2_p)	Phase Specific Comparisons		
	P1 (n)	P2 (n)	P3 (n)			P1 – P2	P2 – P3	P1 – P3
Shoulder Internal Rotation R	61.4 ± 12.6 (57)	64.6 ± 14.5 (46)	65.6† ± 12.0 (36)	0.005*	0.129	0.004	------	------
Shoulder Internal Rotation L	58.1 ± 11.4 (56)	62.2 ± 12.8 (45)	59.5 ± 11.5 (37)	0.019*	0.091	0.015	------	------
Shoulder External Rotation R	43.2 ± 5.6 (57)	42.8 ± 6.7 (46)	41.8 ± 5.4 (36)	0.161	------	------	------	------
Shoulder External Rotation L	43.0 ± 5.8 (56)	43.9 ± 6.5 (45)	41.8 ± 5.3 (37)	0.032*	0.084	------	0.027	------
Knee Flexion R	143.9† ± 33.0 (58)	147.2 ± 25.4 (44)	147.1 ± 22.0 (37)	0.746	------	------	------	------
Knee Flexion L	144.7 ± 24.0 (58)	143.6 ± 25.5 (45)	147.1 ± 22.0 (37)	0.953	------	------	------	------
Knee Extension R	273.2 ± 47.8 (58)	267.6 ± 46.7 (44)	275.0 ± 53.5 (37)	0.480	------	------	------	------
Knee Extension L	265.3 ± 40.1 (58)	257.3 ± 45.7 (45)	284.4† ± 46.0 (36)	0.008*	0.112	------	0.006	------
Trunk Flexion	223.2 ± 35.5 (58)	220.5 ± 39.7 (42)	253.9 ± 43.9 (36)	<0.001*	0.286	------	<0.001	<0.001
Trunk Extension	407.0 ± 75.7 (58)	423.3 ± 86.2 (45)	431.5 ± 66.5 (36)	0.012*	0.105	------	------	0.012

Mean, standard deviation, and number of subjects reported for each phase

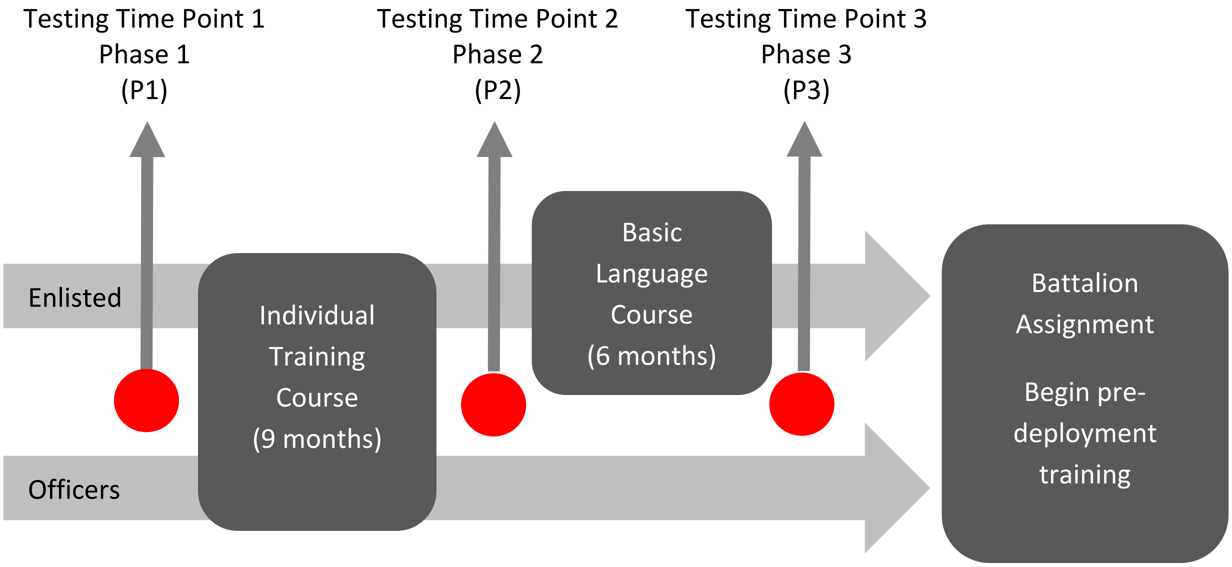
†nonparametric, median and interquartile range reported

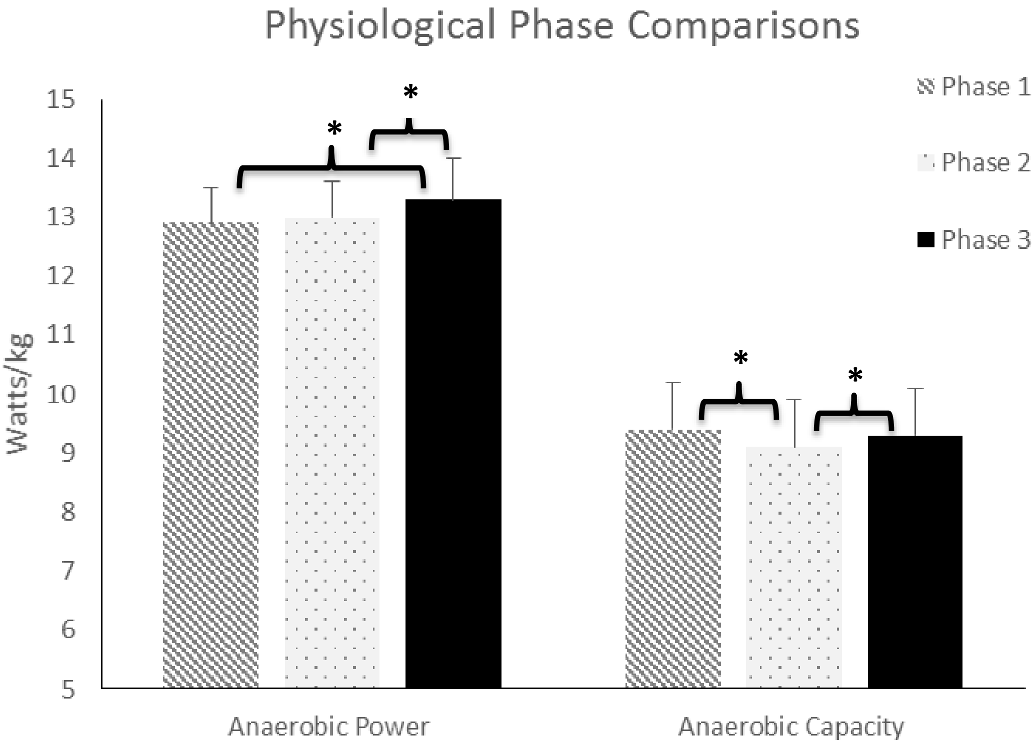
R=right side, L=left side

TABLE 3. FIELD MEASURES

Field Tests	Linear Mixed Model Comparisons			P – Value	Effect Size (η^2_p)	Phase Specific Comparisons		
	P1 (n)	P2 (n)	P3 (n)			P1 – P2	P2 – P3	P1 – P3
Broad Jump (inches)	92.8 ± 6.6 (45)	97.5 ± 6.4 (47)	97.4 ± 6.8 (50)	<0.001*	0.411	<0.001	------	<0.001
5-10-5 Agility (s)	4.97 ± 0.21 (45)	4.88 ± 0.20 (47)	4.83 ± 0.22 (51)	<0.001*	0.279	<0.001	------	<0.001
300-yd Shuttle Run (s)	63.2 ± 2.7 (45)	62.9 ± 2.8 (46)	64.5 ± 3.3 (51)	<0.001*	0.161	------	0.001	0.003

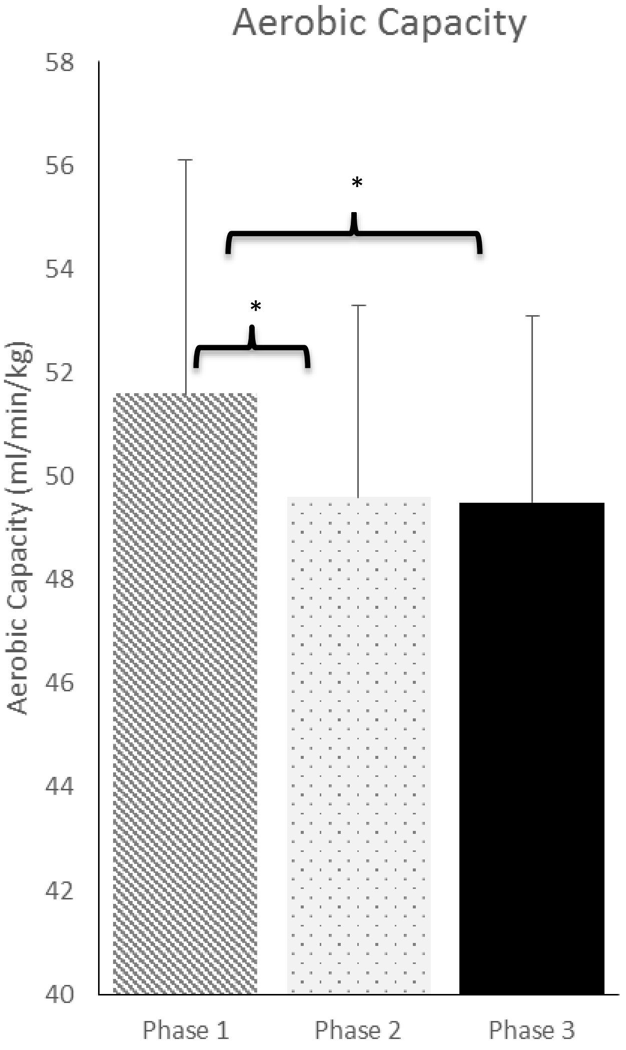
Mean, standard deviation, and number of subjects reported for each phase


Testing Time Point 1
Phase 1
(P1)
Testing Time Point 2
Phase 2
(P2)
Testing Time Point 3
Phase 3
(P3)
Enlisted
Officers
Individual Training Course (9 months)
Basic Language Course (6 months)
Battalion Assignment
Begin pre-deployment training



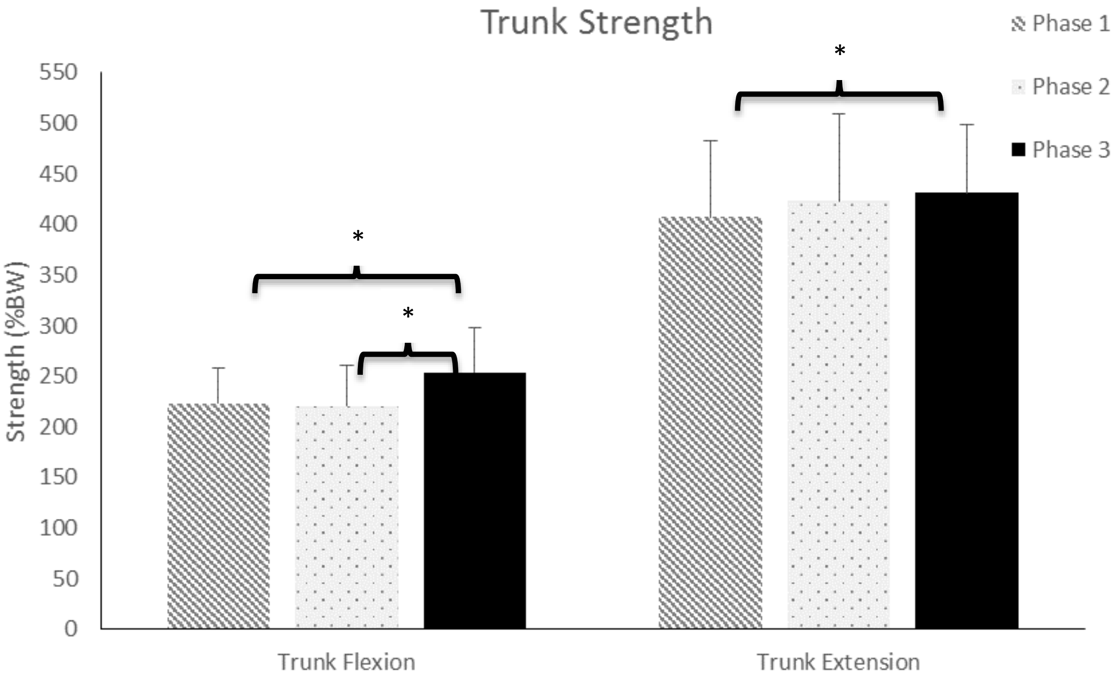
Mean and standard deviation

*indicates significant phase specific pairwise comparisons



Mean and standard deviation

*indicates significant phase specific pairwise comparisons



Mean and standard deviation

*indicates significant phase specific pairwise comparisons

Title: Influence of Limb Dominance and Shoulder Injury on Strength and Explosive Force in US Marines

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Abstract

Purpose/Hypothesis: The specialized roles of many military personnel require specific skills and high physical demands, placing unique stresses on the shoulders and increasing risk of injury. As normal dominant/nondominant shoulder asymmetries have been established in competitive uninjured athletes, as well as military personnel, bilateral strength comparisons must be understood in context of daily physical demands to monitor patients' progress or readiness to return to duty. Presentation of functional deficits following injury may differ between dominant and nondominant side pathology. These differences may require individualized rehabilitation strategies to address deficits specific to the injured side. Therefore, this study aims to assess bilateral differences in strength and explosive force in Marines with a history of dominant or nondominant shoulder pathology.

Participants: A total of 52 full-duty male US Marines (age: 26.76 ± 3.95 years; height: 1.80 ± 0.06 m, mass: 84.89 ± 8.62 kg) with a shoulder injury causing current pain and/or modification of training within the last year participated.

Materials/Methods: Bilateral shoulder internal (IR) and external (ER) rotation strength were assessed at 60° per second using an isokinetic dynamometer in a modified neutral position while bilateral peak forces (Peak Force) and average rate of force production (Avg Rate) during an explosive push-up were collected using two force plates. Dominant versus nondominant side data were independently examined within each group (DOM: dominant shoulder injury, NOND: nondominant shoulder injury). Paired-samples t-tests or Wilcoxon Signed Ranks Tests were used to analyze between-limb differences within each group ($P < 0.05$). Comparison between DOM and NOND as well as previously published CON (no history of shoulder injury) was completed with One-Way ANOVA or Kruskal-Wallis One-Way ANOVA. Post-hoc Bonferroni adjustments were used as appropriate.

Results: NOND (n = 26) demonstrated significantly less IR ($P < 0.001$) and ER ($P = 0.003$) strength and Peak Force ($P = 0.001$) and Avg Rate ($P = 0.047$) on the injured side, while DOM (n = 26) demonstrated no bilateral differences in strength or push-up performance. Comparison between the three groups showed that NOND demonstrated significantly less ER strength than CON (injured nondominant side compared to healthy nondominant side) (One-Way ANOVA: $P = 0.022$; Bonferroni post-hoc analysis between NOND and CON: $P = 0.022$).

Conclusions: Military personnel develop asymmetric strength patterns likely due to increased demand of the dominant shoulder. MARSOC personnel with a history of injury to the nondominant shoulder performed differently than those with a dominant side injury, presenting with both strength and push-up asymmetries. They also demonstrated significant ER strength deficits compared to CON. Common clinical practice and previous literature often compare injured and uninjured limbs or injured individuals to healthy controls, but further distinction of dominant or nondominant side may provide more accurate information needed to develop targeted treatment strategies.

Clinical Relevance: Recognizing unique occupational demands and how patients may present differently with dominant versus nondominant side shoulder injuries are important considerations for ensuring accurate assessment and effective individualized rehabilitation.

INTRODUCTION

The year-round, high intensity, high volume training and deployment cycles required of many Special Operations Forces (SOF) personnel place them at high risk of musculoskeletal injuries.[1] During one pre-deployment work-up, approximately one-third of a Marine Corps Forces Special Operations Command (MARSOC) unit experienced a musculoskeletal injury or physical limitation, which is consistent with other SOF injury rates.[2-4] Shoulder injuries account for approximately 23-24% of all musculoskeletal injuries in SOF personnel[5,6] and 78% of all upper extremity musculoskeletal disorders in MARSOC operators.[7] Such high rates of injury would be expected in overhead athletes[8,9] due to the repetitive motions and extreme shoulder demands of these sports,[10,11] but military personnel also place substantial loads on the shoulder during physical fitness, tactical training, and deployment.[12]

For athletes and military personnel, previous injury is one of the most common risk factors for future injury.[13-16] This increased risk is likely influenced by many factors including changes in motion, proprioception, strength, and function following injury.[17] As the rotator cuff muscles are the primary stabilizers of the glenohumeral joint, a number of studies have analyzed bilateral shoulder internal and external rotation strength deficits following unilateral shoulder injury in athletic and military populations. Internal rotation strength deficits,[18] residual external rotation weakness,[19,20] as well as no asymmetry between the injured and uninjured shoulders[1,21] following return to full activity have all been reported in different studies. While these inconsistencies may be influenced by differences in study populations and varying assessment protocols, comparison is often made between injured and uninjured limbs without consideration of limb dominance.[1,18,21-23] As normal dominant/nondominant shoulder asymmetries have been established in uninjured athletes and MARSOC personnel[24-27] bilateral comparisons must be understood in context of daily physical demands to monitor patients' progress, deficits, or readiness to return to duty. Without limb dominance consideration and/or control group comparison, results may not accurately describe residual deficits or adaptations.

In addition to standardized strength measures, activity-specific functional assessments are encouraged for highly active individuals following injury.[28,29] For athletes, this may include assessment of pitching mechanics or swimming stroke, or other sport-specific tasks. For military personnel, an assessment that represents the explosive requirements of physical and tactical training should be considered. Asymmetries in functional performance on an explosive push-up have been found in healthy MARSOC personnel,[27] therefore, those with a history of dominant or nondominant side shoulder injuries may perform differently on such task if not fully recovered.

With high tempo training cycles, any lingering deficits may be detrimental to operational readiness and increase the risk of sustaining a more severe reinjury. Shoulder strength and functional asymmetries have been established in healthy MARSOC personnel,[27] however, the relationship between performance and limb dominance in those with previous shoulder injury needs to be understood to provide clinicians with a more complete understanding of potential deficits and ways to better treat these individuals. Therefore, this study aims to assess differences in shoulder strength and explosive force in MARSOC personnel with a history of dominant or nondominant shoulder pathology. We hypothesis that those with a history of dominant and nondominant shoulder injuries will display unique strength and functional deficits on the injured side. Additionally, we hypothesize that the identified deficits will be greater than observed in MARSOC personnel with no history of shoulder injury.

METHODS

Participants

Participants in this study were extracted from a larger longitudinal study from August 2015 to December 2017. Participants included MARSOC Operators as well as students and selectees in training to become MARSOC Operators. All participants were cleared for full and unrestricted participation in physical and tactical training. Participants were advised to limit strenuous physical training, and avoid caffeine, nicotine, and alcoholic beverages twenty-four hours prior to testing. Approval was obtained for all research procedures from the University's Institutional Review Board. Written informed consent was obtained from each subject prior to participation in the study.

Injury History

All participants were interviewed by an experienced clinical researcher and asked to describe all musculoskeletal injuries ever sustained that required the individual to stop or modify training for at least one full day, to include any *injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.) that caused the participant to stop or modify training or physical activity for at least one day, regardless if medical attention was sought.* Demographic and descriptive injury data were directly entered into a customized online survey application (REDCap electronic data capture tools hosted at the university[30]) during each interview. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources. Collected injury data included descriptions of anatomical location, anatomical sub location, mechanisms of injury, treatment received for injury, and if they were currently experiencing pain/ modifying training due to the injury.

Laboratory Data

Shoulder Strength

Concentric shoulder internal and external rotation strength were evaluated bilaterally on an isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) at 60 degrees/ second consistent with previously published protocols.[31] Isokinetic strength testing on the Biodex has been found to be a reliable and valid strength measure.[32] Strength was determined by averaging 5 maximal repetitions and analyzed relative to body weight. Side to side deficits were calculated by dividing (injured side/ uninjured side) x 100.

Dynamic Shoulder Function

To evaluate dynamic shoulder function, participants performed an explosive push-up task. Participants started in a prone position with the elbows bent and each hand placed on a separate force plate (Type 9286BA, 60 cm × 40 cm platform; Kistler Instrument Corp., Amherst, NY) at approximately chest level. The force plates were mounted flush with surrounding custom-built flooring so feet and hands were level. Participants were instructed to keep both back and legs straight, feet together, and elbows in a neutral position. When the researcher instructed "rise-up," the participant lifted his chest approximately one inch off the ground. Once this position was attained and held for one second, the researcher instructed "go," at which time the participant performed an explosive push-up, pushing completely off the force plates. The participant was instructed that the goal of the task was to perform the most explosive push-up possible. Participants were given at least one practice trial, followed by three collected trials. A similar protocol has previously been described with excellent relative reliability (ICC= 0.91- 0.96).[33]

Vertical ground reaction force (VGRF) data were collected at 1200 Hz using Vicon Nexus Software (Vicon Motion Systems, Centennial, CO). VGRF analog signals were low-pass filtered with a Butterworth fourth-order zero-phase-shift lag with 50 Hertz cut-off using C-Motion Visual 3-D (C-Motion, Germantown, MD). All data processing was completed in C-Motion Visual 3-D and output variables included peak VGRF (Peak Force) during the concentric phase of the push-up movement and average rate of force production (Avg Rate). Avg Rate was defined as the rate of change in the force between the start of the movement and the peak force and was calculated as the mean of the first derivative of the VGRF. The three trials were averaged for each variable (Peak Force and Avg Rate) for each side and normalized to body weight by dividing by mass.

Subject Classification

REDCap injury data was queried based on "shoulder" location. Shoulder injuries included conditions such as sprains, strains, labral tears and fractures affecting the shoulder joint or clavicle but not contusions or lacerations. Marines reporting a shoulder injury causing current pain and/or modification of training within the last year were classified into the injured group (INJ). Participants were then further differentiated into those that reported a dominant side injury (DOM) and those that reported a nondominant side injury (NOND). Previously published data from MARSOC personnel with no history of shoulder injury (CON) is referenced as well.[27] Marines with history of bilateral shoulder injury, regardless of timing of injuries, or surgical intervention were excluded. Participants with only unilateral strength data were also excluded.

Statistical Analysis

Descriptive statistics were calculated for demographic, strength, and push-up variables. All variables were assessed for normality and frequency distribution. Paired-samples t-tests for parametric data and Wilcoxon Signed Ranks Tests for nonparametric data were used to compare dominant to nondominant sides within each group. Independent samples *t* tests or Mann-Whitney U test were used as appropriate to compare INJ to CON (injured side compared to dominant side of healthy group). One-Way ANOVA or Kruskal-Wallis One-Way ANOVA with post-hoc Bonferroni analyses were used as appropriate to compare DOM, NOND, and CON. For consistency, medians and interquartile ranges are presented in all figures. An alpha level of 0.05 was set a priori to denote statistical significance for all comparisons. Statistical analyses were performed using IBM SPSS Statistics Version 22 (IBM Corp, Armonk, NY).

RESULTS

A total of 52 full-duty male MARSOC personnel with a history of a shoulder injury (age: 26.76 ± 3.95 years; height: 1.80 ± 0.06 m, mass: 84.89 ± 8.62 kg) were included in analysis. Of these, 26 participants reported a dominant side shoulder injury and 26 reported a nondominant side injury. Demographic information for each group, as well as the previously published CON (n = 195), are presented in Table 1.

INJ demonstrated significantly less ER strength ($P = 0.012$) and Avg Rate (all $P = 0.024$) on the injured side compared to the uninjured side but no difference in IR strength ($P = 0.159$) or Peak Force ($P = 0.058$). When comparing the dominant side of CON to the injured limb of INJ, those with a history of shoulder injury were significantly weaker in IR (*P* = 0.023) and ER (*P* = 0.003) strength but no differences in push-up variables were found (Figure 1).

Side to side comparisons within NOND revealed bilateral asymmetry patterns (Figure 2). NOND demonstrated significantly less IR strength (*P* < 0.001), ER strength (*P* = 0.003), Peak Force (*P* = 0.001) and Avg Rate (*P* = 0.047) on the injured side compared to uninjured side. DOM, however, demonstrated no bilateral differences in strength or push-up variables (all *P* > 0.05). As previously reported, CON demonstrated significantly less IR strength (*P* < 0.001) and Peak Force (*P* = 0.037) on the nondominant side but symmetrical ER strength (*P* = 0.137) and Avg Rate (*P* = 0.899).[27] No significant between group differences were found when comparing CON, DOM, and NOND dominant side variables (*P* > 0.05). Nondominant side comparison between the three groups showed that NOND demonstrated significantly less ER strength than CON (One-Way ANOVA: *P* = 0.022; Bonferroni post-hoc analysis between NOND and CON: *P* = 0.022).

DISCUSSION

Due to the upper body demands of training and missions, MARSOC personnel are at high risk of shoulder injuries[7,34] The initial analysis of all injured individuals revealed significant strength deficits compared to healthy controls but mixed bilateral performance asymmetries. Though a convenient and common analysis,[1,18,21-23] comparing injured/uninjured groups or injured/uninjured limbs does not account for differences due to limb dominance. Therefore, the main purpose of this study was to determine if consideration of limb dominance with side of injury further differentiated deficits in shoulder strength and function in MARSOC personnel. Consistent with our hypothesis, strength and functional asymmetries differed between those with a history of dominant and nondominant side injuries. Furthermore, strength deficits on the injured side were identified for those with a nondominant side injury compared to healthy controls.

Our results support distinguishing side of injury based on limb dominance as unique asymmetry patterns were revealed. DOM demonstrated no asymmetries in strength or push-up performance, while conversely, NOND performed significantly worse on the injured/nondominant side in IR and ER strength as well as both explosive push-up performance measures. Initial review of our assessments might suggest that DOM had fully recovered from injury as they demonstrated symmetrical strength and push-up performance, however, this may be misleading as this pattern is different from that of CON. In contrast, as NOND demonstrated significant deficits on all assessments on the injured side within group, they may appear to have greater deficits than DOM. However, as CON was not symmetrical, complete symmetry may not be realistic in this population. These distinct patterns of decreased symmetry for NOND and increased for DOM are muddled when all are considered as one injured group. Though different populations, our results mirror those of a study by Edouard et al.[35] of patients with recurrent unilateral anterior shoulder instability. They concluded that in those with dominant side involvement, asymmetries decreased and for those with nondominant shoulder involvement, side-to-side differences increased.[35]

While grouping all shoulder injuries together may mask within group asymmetries, this same grouping may amplify deficits in comparison to a healthy control group. The findings of IR and ER deficits for INJ compared to CON may be misleading as this is a comparison of both dominant/nondominant injured shoulders to only the dominant side of CON. Although the only difference found between groups when considering limb dominance was an ER deficit in NOND compared to CON, this finding is particularly relevant to a military population, whose work load may vary substantially between training and deployment cycles. In a study of handball players, Møller et al.[36] found that shoulder injury rate was significantly greater in those that increased their playing load by 60% relative to the weekly load over the previous 4 weeks. Furthermore, those with decreased ER strength were more prone to shoulder injuries at moderate (20-60%) increases in training load and even greater risk at high load (>60%) increases.[36] Given these findings and the deficits found in ER, full recovery of ER strength following injury should be prioritized.

Residual deficits following shoulder injuries have been studied in other special operations military populations.[1,21] Deficits in either IR or ER strength have been reported in SOF personnel with history of a shoulder injury when comparing the injured side to the right side of healthy controls.[1,21] In these studies, bilateral strength differences of greater than 10% were reported in a substantial portion of the injured participants.[1,21] For example, in Navy SEALs, between 20% and 22% of participants demonstrated a greater than 10% deficit on their injured side in IR and ER strength respectively.[1] Despite these deficits, SOF personnel with a history of shoulder injury were found to be symmetrical in IR and ER strength.[1,21] As injured personnel were grouped together, without consideration of limb dominance, side to side differences and between group comparisons may be misleading. By differentiating those with a dominant and nondominant side injuries in MARSOC personnel, distinct symmetry patterns and deficits were found. Nearly 54% of NOND demonstrated a greater than 10% deficit in IR strength on the injured side, compared to only 17% of DOM. Similarly, for ER strength, 27% of NOND demonstrated a greater than 10% strength deficit compared to only 13% of DOM. Again, these findings support consideration of limb dominance in side of injury for bilateral comparison as well as Edouard et al.'s[35] conclusion that asymmetries are more prominent following a nondominant side injury involvement and reduced when the dominant side is involved.

In an ever-demanding environment, the balance between adequate recovery following injury and mission readiness must be carefully considered. Accurate clinical interpretation of assessment measures properly informs decisions regarding treatment planning and return to activity. Though a patient may present with symmetrical strength and performance, he may be at risk of reinjury if this does not accurately depict his prior level of function. In contrast, another patient may not be able to reach perfect side-to-side symmetry following a nondominant side injury if he heavily relies on his dominant side for performance tasks. Although manual muscle testing is a common assessment for monitoring strength progression, minor impairments typically cannot be captured, even at the shoulder. Individuals who demonstrate bilateral normal shoulder strength (5/5) with manual muscle testing, may still show significant bilateral differences of 13-28% when tested via isokinetic dynamometry.[37] Therefore, sensitive and quantifiable assessments, such as hand-held dynamometry, submaximal or maximal strength testing and functional assessments should be considered as appropriate. While this study is specific to MARSOC personnel, the findings suggest that limb dominance should be considered in rehabilitation for military personnel and are likely applicable across SOF communities. Daily physical demands, typical presentation in the given population, and prior level of function should all be weighed in the clinical decision-making process.

The current study does have some limitations. Injury diagnoses were not differentiated in the analysis. Certain pathologies may affect individual muscle groups and therefore performance, differently. Though injury severity likely differed between participants, all had stopped or modified training due to the injury for at least one full day within the last year and none were treated operatively. There were also similar distributions of acute and chronic injuries as well as diagnoses and medical encounters between DOM and NOND. Additionally, while all the participants in this study were MARSOC Operators or students/selectees preparing to become Operators, many were in different phases of training as well as different career timepoints. Such differences in current training demands could affect performance but is representative of the varying demands of this environment. Finally, as self-reported injury information may be limited by participant recall, injuries were restricted to those that influenced pain and/or activity within the last year.

CONCLUSIONS

Military personnel demonstrate asymmetric strength patterns likely due to increased demand of the dominant shoulder. MARSOC personnel with history of injury to the nondominant shoulder performed differently than those with a dominant side injury, presenting with both strength and push-up asymmetries. Common clinical practice and previous literature often compares injured and uninjured limbs or injured individuals to healthy controls,[1,38,39] but further distinction of dominant or nondominant side may provide more accurate information needed to develop targeted assessments and treatment strategies. Recognition, with individualization of rehabilitation, may lead to improved patient outcomes and decreased risk of re-injury following a shoulder injury.

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Human Performance Training Program Utilization and Training Outcomes in United States Marine Corps Forces Special Operations Command Operators

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Abstract:

To meet physical occupational demands, Marine Corps Forces Special Operations Command (MARSOC) has implemented a human performance training (HPT) program. The utilization and performance adaptations of this voluntary HPT program are not known. The aim of this study was to describe the utilization characteristics and performance adaptations of the HPT program. Entry-level operators (n=45, Age:25.6±2.5 years, MARSOC Experience:0.76±0.07 years) were tested at the beginning (Pre) and following 8-weeks (Post) of MARSOC's Basic Language Course. Use of the HPT program was recorded by MARSOC human performance personnel. Pre and post trunk, shoulder and knee strength, anaerobic power, and aerobic capacity were measured. Data were analyzed for all operators as well as comparing low (LU, <2) and high (HU, ≥3 sessions/week) utilizers. Use of the HPT program for all operators decreased over the 8-weeks (2.04±1.78 to 0.93±1.39 sessions/week, $p<0.05$). When data from all operators were analyzed, increases in trunk flexion ($p<0.001$), right shoulder external rotation ($p=0.020$), left knee extension ($p=0.044$), peak ($p<0.001$) and mean anaerobic power ($p<0.001$) were observed. Twenty-four operators were classified as LU (0.45±0.62) and 15 as HU (3.58±0.31 sessions/week). There were no significant differences in training outcomes between the LU and HU groups. Utilization of the HPT program varied between and within individuals. Additional improvements in performance outcomes may require longer or more consistent use of the program. Additional research is required to understand the barriers to program utilization to improve its effectiveness.

INTRODUCTION:

Military personnel are regularly exposed to physically demanding tasks and environments [1,2]. To meet these physical requirements, physical fitness has long been a pillar of military training and a requirement to enter and remain in military forces around the world [3-5]. While physical fitness is required for optimized execution of military maneuvers, physical fitness is also an important consideration in reducing the risk and incidence of musculoskeletal injuries [6,7].

In order to comply with physical fitness requirements and reduce the risk of musculoskeletal injury, physical training programs have been developed and implemented in a wide range of military forces and populations [8-12]. The successful design and implementation of these programs are critical for special operations operators who are exposed to variable tasks and environments [1,2,13], an expected higher operational capacity, and an increased tempo of deployments and missions on deployment [2].

The United States Marines Corps Forces Special Operations Command (MARSOC) trains US Marines to execute a wide variety of complex operations in challenging and unpredictable environments. The human performance training program (HPT) implemented by MARSOC has been designed to optimize the muscular groups and energy systems that closely resemble the occupational requirements of MARSOC operators. The program has been designed to increase strength, anaerobic and aerobic components of fitness while also reducing the incidence of injury by training stabilizing muscles around commonly injured joints such as the shoulder and knee. Specifically, the program provides workouts utilizing bodyweight-, free weight-, power-, Olympic lift- and high intensity interval-based training for operators with a wide range of physical fitness and training experience.

While the HPT program is designed to increase force readiness and resiliency, the program is not mandatory. MARSOC operators are encouraged to utilize the HPT program but may use alternative training methods and programs if desired. When using the HPT program, operators can choose from over fifty different workouts, and have the opportunity to receive individualized supervision from a strength and conditioning coach. While previous studies have focused on the physical performance outcomes associated with a given training program [8-11], the utilization of military physical training programs is not known. If the developed training programs are not utilized, the performance and injury prevention benefits of the program may not be achieved and the operational capacity and resilience of the military force could be compromised.

It is essential therefore, that training adaptations are assessed in conditions where utilization of the program is not controlled or mandatory. The aim of this study was to describe the utilization characteristics and performance adaptations of the MARSOC HPT within a regular training environment. Utilization was assessed in entry-level MARSOC operators during the Basic Language Course (BLC) phase of training. It was hypothesized that increases in strength, anaerobic capacity and aerobic capacity would be highest in operators with the greatest utilization of the human performance program.

METHODS:

Experimental Approach to the Problem:

A cohort of entry level MARSOC operators were tested at the beginning (Pre) and after 8-weeks (Post) of an intensive language course at the Marine Training Center. Operators were tested in a laboratory for changes in body composition, anaerobic power, isokinetic strength and maximal aerobic capacity. During the 8-weeks of the language course, operator utilization of the HPT program was documented by strength and conditioning coaches at the HPT training facility. All testing was repeated within 8-11 weeks of the Pre-testing.

Participants:

A total of 45 entry level MARSOC operators from Class A (n=19) and Class B (n=27) volunteered for the study (Table 1). The study was approved by the University's Institutional Review Board. Each participant gave written, informed consent prior to participation in the study in accordance with the standards set by the Declaration of Helsinki. All participants completed a medical questionnaire prior to participating in the study. Any operator who was not cleared for full and unrestricted participation in physical and tactical training, as well as any participant who suffered a musculoskeletal injury resulting in missed training or medical treatment during the eight weeks were excluded from the study. Due to limited availability, not all operators completed the entire assessment protocol. Only data in which an operator failed to complete the pre or post-testing assessment (i.e. completed the assessment at Pre- or Post-testing only), were excluded from the analysis. Participant characteristics, including years of MARSOC and US Marines experience, are detailed in Table 1.

Procedures:

Pre and Post testing followed the same protocol for each testing session. Upon arriving at the laboratory, participants completed the following assessments in the same order for each visit: body composition, anaerobic power, isokinetic strength and maximal aerobic capacity. Participants rested for no less than 20 minutes between the anaerobic power, isokinetic strength and maximal aerobic capacity testing. Each assessment was fully explained to each participant before completing the assessment.

Body Composition: Height (cm) and weight (kg) were measured using a stadiometer and digital scales respectively. Body composition was measured via air displacement plethysmography (Bod Pod; Cosmed, Chicago, IL, USA). Participants were tested while wearing only spandex shorts and a swim cap to reduce air displacement. Body composition is reported as body fat (%) and fat free mass (kg).

Strength: Isokinetic strength of the trunk as well as around the shoulder and knee were measured (Biodex Multi-Joint System 4 Pro, Biodex Medical Systems, Shirley, NY). The strength measurements were selected so as to compare MARSOC operators with previously collected data in U.S. Special Operations operators [8,12,14]. Following a brief warm-up, trunk flexion/extension strength, shoulder internal/external rotation strength and knee flexion/extension strength were measured as the average peak torque of five consecutive repetitions ($60^{o}.sec^{-1}$). Coefficient of variation (CV) for peak torque throughout each measurement trial was measured and if the CV was greater than 15%, the assessment was repeated following sufficient recovery. All values are reported as mean peak torque (Nm).

Anaerobic Power and Capacity: Anaerobic testing was performed on a magnetically-braked cycle ergometer (VeloTron, RacerMate, Seattle, WA). Participants completed a 5-minute warm up (125W) at a self-selected cadence. Following the warm-up, participants completed a 30s maximal test in which they were instructed to pedal as hard and as fast as possible throughout the entire duration of the test, whilst maintaining a seated position and holding the top of the handlebars. Following three seconds to increase cadence as quickly as possible, a 9.0% body weight braking torque was immediately applied and maintained for the remaining 30 seconds. Peak anaerobic power was calculated as the peak power during the test. Mean anaerobic capacity was calculated as the mean power throughout the 30 seconds. Peak anaerobic power and mean anaerobic capacity are reported relative to body weight ($W \cdot kg^{-1}$).

Aerobic Capacity: VO_2max and lactate threshold were determined from an incremental treadmill test to volitional exhaustion. Participants performed a 5-minute warm-up before the speed was increased and incline increased by 2% every 3 minutes to exhaustion. Warm-up and incremental speeds were determined from the participants last known 3 mile run time. VO_2 (TrueOne 2400, ParvoMedics, Sandy, UT) and heart rate (Polar USA, Lake Success, NY) were measured throughout the protocol. Blood lactate was measured during the final minute of each stage (Lactate Pro, Arkray Inc, Kyoto, Japan).

Statistical Analyses:

Comparisons between baseline testing and 8 week testing for all operators were made using paired t-tests. To determine the effect of HPT program utilization on training outcomes, students were classified to high utilization (HU, $\geq$3 sessions per week) and low utilization (LU, <2 sessions per week) groups. These thresholds represent $\geq$50% (HU) or $\leq$50% (LU) of an operators estimated 4-6 weekly training sessions.

Participant characteristics between the HU and LU groups were analyzed using unpaired t-tests. Pre and Post performance data of the HU and LU groups, as well as utilization of the HPT program (all operators, HU group and LU group) throughout the 8-weeks were analyzed using a repeated-measures ANOVA. In all statistical analyses significance was set at $p<0.05$. All data are presented as mean ±SD.

RESULTS:

Program Utilization: Fifteen operators were classified as high utilizers and 24 operators were classified as low utilizers (Table 1). There were no significant differences in demographics or military experience between the HU and LU groups. There was a significant decline in utilization from Week 1 to Weeks 7 and 8 for all operators and the HU group (Figure 1). In the LU group, utilization was significantly less during Weeks 4, 5, 7 and 8 when compared to Week 1.

Body Composition: When data for all operators were combined, body mass ($p<0.001$) and fat free mass ($p=0.044$) significantly increased from baseline to Week 8 (Table 2). There was no significant change in body fat percentage. Body mass, fat free mass and body fat percentage were not significantly different between the HU and LU groups (Table 2).

Isokinetic Strength: For all operators combined, trunk flexion significantly increased from baseline to 8-week testing ($p<0.001$), which significantly decreased the trunk extension to flexion ratio ($p<0.001$, Table 3). There were also small but significant increases in right shoulder external rotation ($p=0.020$, Table 4) and left knee extension ($p=0.044$, Table 5) as well as a decrease in right knee flexion to extension ratio ($p=0.030$, Table 5). There were no significant differences in trunk or shoulder strength variables between the HU and LU groups. Left ($p<0.001$) and right ($p=0.006$) knee flexion to extension ratios were greater in the LU group at baseline and 8 weeks when compared to the HU group.

Anaerobic Power and Capacity: For data from all operators, anaerobic power ($p<0.001$) and capacity ($p<0.001$) significantly increased from baseline to 8 weeks (Table 6). There were no significant differences between HU and LU groups.

Aerobic Capacity: There were no significant changes in VO_2max or lactate threshold, or any significant differences between the HU and LU groups (Table 6).

DISCUSSION:

The aim of this study was to describe the utilization and training outcomes from the MARSOC HPT program over 8 weeks of training. The key finding from the present study was the variable utilization of the program between and within individuals. Over half of the operators studied used the program less than two sessions per week, and utilization decreased throughout the 8-weeks in all groups. Despite lower utilization, the physical outcomes of the low utilizers were similar to those who were high utilizers of the program.

Due to the high physical demands imposed on special operations military personnel, there is a need to design and implement appropriate physical training programs. A range of programs in US and international special operations forces have been trialed, with all reporting improvements in physical performance [8-12]. However, in each of these trials, a specific training program with minimum participation requirements was examined in order to assess the utility and performance adaptations from the training program. The present study is the first study to assess physical training program outcomes based on the utilization of a voluntary, uncontrolled program.

The utilization outcomes of the present study showed that there were wide variances in the use of the program between individuals. It is beyond the scope of this study to be able to explain why some operators chose not to regularly use the HPT program, while others did. No study in military personnel has investigated the utilization of a specific program or attitudes towards use/non-use of a program. Therefore, we are unable to compare to any existing data, but variations in exercise goals and program design have been observed in other tactical populations. In a national cohort of special weapons and tactics (SWAT) law enforcement personnel, 49% of respondents designed their own physical training program [15] but only 31% used a program designed by a Commander or a certified fitness professional. In addition, there was a range of training goals amongst the cohort. Additional research is needed to ensure physical training programs meet occupational physical requirements of military personnel, as well as being adaptable to individuals training goals, times and locations.

In the present study, utilization of the MARSOC HPT program also declined over the 8-weeks in all groups. It is unknown what caused the decrease over time, however the significant decrease of all operators, the HU group and the LU group in weeks 7-8, suggest it could be due to other course or training requirements. A key issue when designing and implementing physical training programs for special operations personnel, is the immense volume of technical and tactical training the operators are required to complete [2]. The decision to assess entry-level operators within this study was made because the language course is a classroom-based course and testing and training would not be externally influenced by additional technical or tactical training. However, it is possible that due to the workload of the course, availability for physical training was still compromised. It is also possible that the utilization of the program is different in fully trained and experienced MARSOC operators or at different time-points in the training and deployment cycle.

Considering the variability and inconsistency in the use of the MARSOC HPT program within and between participants, it is not surprising that inconsistent changes in performance were observed. Pre-testing strength, anaerobic capacity and aerobic capacity in the present study showed the MARSOC operators to be comparable with other US special operations operators [8,12,14]. Significant but small improvements in the same performance measures as the current study were observed following eight [12] and twelve [8] weeks of training in US Navy and Army special operations, respectively. However, in each of these studies, volunteering for the study also included volunteering to strictly follow the designated training program (experimental groups only) and compliance was closely monitored.

In the present study, where participants were not assigned to an experimental or control group, the training adaptations were mostly insignificant. Trunk flexion, anaerobic power, and anaerobic capacity were the only variables to consistently increase across all groups. Given the high baseline measurements of the MARSOC operators, indicating a highly trained cohort, and the large variance in utilization of the MARSOC HPT program, it is unlikely that differences between the high and low utilizers would be significant following 8 weeks of training. It may be that highly consistent use as per the previous studies [8,12], or a longer time frame may be needed for significant differences in training adaptations to occur. The long-term effect of HPT utilization on performance and injury prevention remains unknown.

Due to the participant population, and the varied training schedule, this study has a number of limitations. In addition, there was little time for extensive familiarization of the equipment and protocols. However, every effort was made to ensure that each assessment was a true measure of each individual’s maximal capability. A limitation of assessing program utilization via attendance only, is it does not capture what type of exercise or the intensity of the exercise that operators were doing. If operators chose only to focus on specific workouts within the HPT program, training adaptations would heavily favor the movements and muscle groups involved in that specific workout. In addition, we were unable to quantify what external training the operators were doing as it was outside the scope of the present study. The additional questions including workout-specific utilization, alternative training utilization and methods, and personal fitness goals require further research.

CONCLUSIONS:

In summary, utilization of the MARSOC HPT program varied greatly between and within individuals. Due to the inconsistent use of the program, the absence of significant training adaptations is expected. Future research is needed to understand why many operators chose to use the program so infrequently and what alternative training methods they were using. Only when we understand why operators choose or choose not to use appropriately designed programs, can the utilization of the program, the supervision from the training staff, and thus the performance and injury prevention benefits of the program be maximized.

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Table 1. Operator characteristics for all operators, low utilizers (LU) and high utilizers (HU)

	All Operators (n=45)	LU Operators (n=24)	HU Operators (n=15)
Age (years)	25.6 ±2.5	26.3 ±2.8	25.2 ±2.0
Height (cm)	179.7 ±6.9	179.7 ±4.8	182.1 ±8.4
Weight (kg)	85.3 ±8.3	86.5 ±8.2	85.3 ±8.7
MARSOC Experience (years)	0.76 ±0.07	0.77 ±0.10	0.76 ±0.02
US Marines Experience (years)	5.92 ±1.51	5.93 ±1.41	6.49 ±1.74
HPT Program Utilization (sessions/week)	1.77 ±1.54	0.45 ±0.62*	3.58 ±0.31

*Significant difference to HU Operators ($p<0.05$)

Table 2. Body composition changes following 8 weeks of training

Group	Time Point	Body Mass (kg)	Fat Free Mass (kg)	Body Fat (%)
All	Pre	84.8 ±8.2	71.5 ±7.1	15.7 ±3.5
(n=32)	Post	86.5 ±8.8*	72.5 ±7.0*	16.0 ±4.0
LU	Pre	86.1 ±7.6	73.7 ±5.7	14.3 ±2.6
(n=15)	Post	87.7 ±8.4	74.2 ±6.0	15.2 ±4.1
HU	Pre	85.5 ±8.8	71.4 ±8.1	16.4 ±4.0
(n=12)	Post	87.2 ±9.2	72.6 ±8.0	16.7 ±3.3

All = All Operators, LU = Low Utilization Group, HU = High Utilization Group

*Significant difference to Pre-testing ($p<0.05$)

Table 3. Torso strength changes following 8 weeks of training

Group	Time Point	Torso Flexion (Nm)	Torso Extension (Nm)	Torso Ext:Flex
All (n=27)	Pre	191.35 ±40.18	364.80 ±73.76	1.95 ±0.46
	Post	218.30 ±42.53*	376.22 ±73.92	1.75 ±0.31*
LU (n=17)	Pre	193.24 ±46.50	372.64 ±71.97	2.00 ±0.51
	Post	221.61 ±50.64	377.14 ±71.69	1.74 ±0.34
HU (n=8)	Pre	195.66 ±26.55	366.84 ±80.96	1.89 ±0.43
	Post	221.24 ±17.86	386.49 ±87.74	1.74 ±0.29

All = All Operators, LU = Low Utilization Group, HU = High Utilization Group

*Significant difference to Pre-testing ($p<0.05$)

Table 4. Shoulder strength changes following 8 weeks of training for all participants

Group	Time Point	Left Shoulder External Rotation (Nm)	Right Shoulder External Rotation (Nm)	Left Shoulder Internal Rotation (Nm)	Right Shoulder Internal Rotation (Nm)	Left Shoulder ExR:IntR (Nm)	Right Shoulder ExR:IntR (Nm)
All	Pre	37.59 ±7.24	36.52 ±6.51	55.22 ±14.17	54.92 ±14.48	0.70 ±0.13	0.69 ±0.13
(n=26)	Post	38.30 ±7.25	38.34 ±6.41*	56.65 ±12.11	56.69 ±13.64	0.69 ±0.11	0.70 ±0.14
LU	Pre	38.35 ±7.78	37.42 ±6.61	54.05 ±12.33	54.22 ±11.28	0.72 ±0.08	0.70 ±0.12
(n=13)	Post	39.08 ±5.77	39.79 ±6.38	56.22 ±9.69	55.65 ±10.76	0.71 ±0.11	0.73 ±0.10
HU	Pre	36.55 ±5.93	35.05 ±6.17	56.71 ±18.51	55.57 ±18.34	0.69 ±0.18	0.67 ±0.16
(n=10)	Post	36.77 ±8.49	36.41 ±6.16	57.40 ±16.77	57.45 ±18.74	0.66 ±0.11	0.68 ±0.19

All = All Operators, LU = Low Utilization Group, HU = High Utilization Group

*Significant difference to Pre-testing ($p<0.05$)

Table 5. Knee strength changes following 8 weeks of training for all participants

Group	Time Point	Left Knee Flexion (Nm)	Right Knee Flexion (Nm)	Left Knee Extension (Nm)	Right Knee Extension (Nm)	Left Knee Flex:Ext	Right Knee Flex:Ext
All	Pre	127.24 ±20.81	134.43 ±21.67	233.42 ±41.04	241.73 ±36.02	0.55 ±0.07	0.56 ±0.06
(n=26)	Post	131.46 ±21.81	135.65 ±23.87	243.32 ±49.17*	252.57 ±47.17	0.55 ±0.08	0.54 ±0.07*
LU	Pre	134.78 ±17.50	138.96 ±19.28	221.53 ±24.51	232.16 ±19.68	0.61 ±0.05	0.60 ±0.05
(n=12)	Post	137.83 ±21.73	139.80 ±21.31	233.56 ±40.35	243.45 ±36.90	0.60 ±0.07	0.58 ±0.05
HU	Pre	119.09 ±22.69	130.93 ±26.54	237.82 ±47.50	248.08 ±48.34	0.50 ±0.03$^{\alpha}$	0.53 ±0.05$^{\alpha}$
(n=11)	Post	125.52 ±22.62	135.18 ±27.85	248.00 ±51.68	262.05 ±56.22	0.51 ±0.04$^{\alpha}$	0.52 ±0.06$^{\alpha}$

All = All Operators, LU = Low Utilization Group, HU = High Utilization Group

*Significant difference to Pre-testing ($p<0.05$)

$^{\alpha}$Significant difference to the LU group ($p<0.05$)

Table 6. Anaerobic and aerobic capacity changes following 8 weeks of training for all participants

Group	Time Point	Peak Anaerobic Power ($W.kg^{-1}$)	Mean Anaerobic Power ($W.kg^{-1}$)	VO_2max ($ml.kg^{-1}.min^{-1}$)	Lactate Threshold (%VO_2max)
All	Pre	12.83 ±0.61	9.00 ±0.69	52.41 ±4.09	81.84 ±5.69
(n=42)	Post	13.22 ±0.64	9.25 ±0.76	51.61 ±4.63	83.33 ±4.35
LU	Pre	12.90 ±0.62	8.93 ±0.67	50.70 ±3.13	83.75 ±5.23
(n=21)	Post	13.22 ±0.59	9.08 ±0.76	49.54 ±3.64	84.38 ±4.50
HU	Pre	12.81 ±0.69	9.06 ±0.81	53.42 ±5.16	80.47 ±5.71
(n=15)	Post	13.33 ±0.71	9.42 ±0.81	53.72 ±5.93	81.38 ±4.42

All = All Operators, LU = Low Utilization Group, HU = High Utilization Group

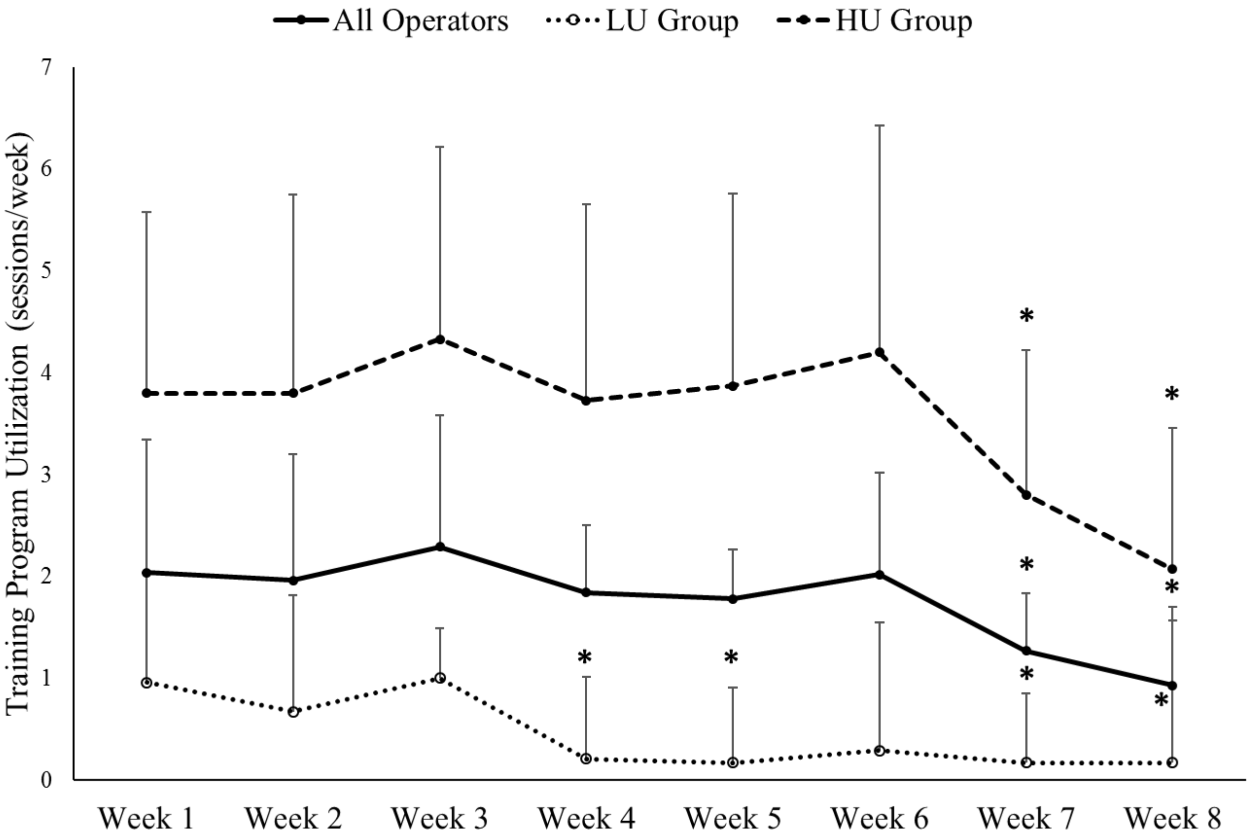

Figure 1. HPT program utilization throughout over 8 weeks of training.

*Significant difference from Week 1 (p<0.05)

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Title: Injuries in Operators and Support Personnel in Marine Special Operations

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Key Words: Military, Musculoskeletal Injury, Incidence

Abstract:

INTRODUCTION: Special Operations Forces Operators (OPs) sustain greater rates of musculoskeletal injuries than conventional forces. In addition to OPs, Marine Corps Forces Special Operations Command (MARSOC) also utilize Combat Support Personnel (CSP), which are critical for mission operations and readiness. Therefore, the purpose of this study was to describe injury epidemiology in MARSOC personnel and compare injury patterns between OPs and CSP.

MATERIALS AND METHODS: A total of 152 MARSOC personnel (98 OPs, 54 CSP) completed an injury history questionnaire to describe musculoskeletal injuries that occurred in the previous 12 months. Injury proportions were calculated and Fisher's exact tests were used to compare proportions.

RESULTS: A total of 71 injuries within the previous 12 months were recorded, 39 of which were classified as preventable and reported by 25 personnel (12 OPs, 13 CSP). There were no statistically significant differences in the proportion of subjects reporting preventable injuries between OPs and CSP. Both OPs and CSP sustained the majority of preventable injuries while performing running and lifting activities (23.3% and 30.2% for OPs and 50.0% and 35.7% for CSP, respectively). OPs and CSPs sustained 34.62% and 59.1% of preventable injuries during physical training related activities, respectively. Also, the lumbopelvic and knee regions were the most commonly reported locations of preventable injuries for OPs (23.1% and 15.4%) and CSP (22.7% and 31.82%).

CONCLUSIONS: OPs and CSP seem to sustain similar injury patterns with similar mechanisms, suggesting CSP should also be included in injury prevention initiatives to optimize force readiness. Additionally, the majority of injuries sustained were preventable and sustained

during physical training, suggesting significant potential benefit from injury prevention programs to mitigate preventable injuries and optimize force readiness.

Introduction

Musculoskeletal injuries are reported to be the leading cause for medical visits within the United States military.[1-3] Special Operation Forces (SOF) are known to sustain a high frequency of preventable musculoskeletal injuries with 0.25 preventable injuries per operators (OPs) per year have been reported in the United States Army SOF.[4] Rates of musculoskeletal injuries based on ICD-9-CM codes among conventional soldiers in the United State Army have been reported to be .004 injuries per person per years,[5] a rate much lower than what has been reported in SOF. An epidemiological analysis of musculoskeletal injuries in Naval Special Warfare operators reported the frequency of musculoskeletal injuries to be 0.3 per operator per year.[6] Although the reasons for this difference are likely multifactorial, it is hypothesized that there is a greater exposure to risk of injury in the SOF communities due to higher training demands and a higher deployment tempo.

Although previous injury epidemiology research within the SOF community has focused on operators, Combat Support Personnel (CSP) are a critical group that has not been addressed. Within the Marine Corps Forces Special Operations Command (MARSOC), CSP are operational and tactile force multipliers that deploy alongside OPs. These CSP are crucial members of the military taskforce and may include, but is not limited to, corpsman, intelligence, and communications specialists. These personnel are responsible for the creation of defense plans, analyses of intelligence data, knowledge of hostile environments, assessment of risk, and use of foreign language (translated, interrupted, or transcribed). These areas of expertise make CSP deployable assets that are critical to mission readiness and execution.

CSP require additional training and qualifications prior to being attached to a MARSOC battalion or team; however, they do not have the same training process. They often face high physical demands and this may place them at an increased risk of injury. Although injuries to OPs are detrimental for operational readiness,[7] injuries sustained by CSP also critically affect operational readiness and team safety. As CSP are a large proportion of personnel within MARSOC, making up about one-third of total personnel, understanding injury patterns in this sector is indispensable to combat teams and mission readiness.

The readiness of CSP are equally important in SOF as the readiness of OPs but the characteristics and incidence rates of musculoskeletal injuries among CSP compared to OPs are unknown. Although CSP are acquired by SOF from military occupational specialties within conventional forces, their demanding role within SOF such as MARSOC may create unique injury characteristics, distinct even from OPs. Therefore, the purpose of this study was to identify injury characteristics among MARSOC OPs and CSP. This data will provide critical evidence to identify population-specific injury prevention needs for future optimization initiatives to improve overall force readiness.

Methods

A total of 219 Marines from the Marine Corps Forces Special Operations Command (MARSOC) participated in this research study, 153 operators (OPs, age = 27.6 ± 4.9 years, height = 178.8 ± 6.6 cm, weight = 84.6 ± 9.3 kg), 66 combat support personnel (CSP, age = 27.5 ± 4.9 years, height = 178.6 ± 6.6 cm, weight = 84.5 ± 9.3 kg). Years of service within MARSOC ranged from 0-5.5 (OPs) and 0-10 (CSP). Inclusion criteria included MARSOC membership, cleared for full and unrestricted participation in physical and tactical training, and free of injury to arms, legs, back, and neck within the past month that led to training cessation or medical treatment. All research procedures obtained approval from the University’s Institutional Review

Board. Written informed consent was obtained from each subject prior to participation in the study.

Self-reported injury history was collected on MARSOC personnel. All subjects were interviewed by an experienced clinician and asked to describe all musculoskeletal injuries that had occurred in the previous 12 months from the interview date. Demographic and descriptive injury data were directly entered into a customized online survey application (REDCap electronic data capture tools hosted at XXXXXX)[8] during each interview or a paper form was used if computer access was not possible and later transcribed into the system. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources. Collected injury data included descriptions of anatomical location, anatomical sub location, cause of injury, mechanisms of injury, and treatment received for injury.

For the purpose of this study, a musculoskeletal injury was defined as an injury to the musculoskeletal system that resulted in alteration of tactical, occupational, or physical training activities for at least 24 hours. Seeking treatment was not required for an event to be classified as an injury. Injuries were further classified as preventable or not preventable. Preventable injuries were defined as injuries that potentially could be reduced through improvements in neuromuscular and physiological characteristics related to risk of musculoskeletal injury, or modification of physical training characteristics. Classification of injuries was performed by two experienced research clinicians. If a disagreement between the two clinicians was found, a third clinician was surveyed. This definition was designed to exclude traumatic injuries such as motor vehicle accidents, aircraft accidents, blunt force trauma, and gunshot-related trauma. Examples of preventable musculoskeletal injuries include non-contact lower extremity ligament injuries, lower extremity stress fractures resulting from running and/or marching and overloading/overtraining related injuries. The operational definition of preventable musculoskeletal injuries is specific to the research groups interested in the development of injury prevention strategies through training.

Statistical Analysis

Self-reported injury data were summarized using descriptive statistics, including relative frequency distributions and proportions. Injury frequency was reported as the number of injuries per 100 subjects per year; injury incidence was reported as injuries per 100 person-years. Injury proportions were calculated separately for OPs and CSP; comparisons between the two groups were assessed using Fisher's exact tests. Data were analyzed using SPSS statistical software (version 23.0; IBM Corporation, Armonk, NY) with an alpha level of 0.05 used throughout.

Results

Across all 219 participants, a total of 76 preventable musculoskeletal injuries were identified in the previous 12 months; 57 OP injuries (37.3% of OPs) and 19 CSP injuries (28.8% of CSP) were reported. The incidence rate of total injuries was 34.7 per 100 person-years. The incidence of injuries in OPs was 37.3 injuries per 100 person-years and in CSP 28.8 injuries per 100 person-years. The majority of reported injuries were preventable in both OPs and CSP (OPs

= 75.4%, CSP = 73.7%), as seen in Table 1. The incidence for preventable injuries in OPs was 28.1 per 100 person-years and 21.2 injuries per 100 person-years in CSP.

The reported mechanisms for the majority of preventable injuries were running (OPs= 23.3%, CSP= 50.0%) and lifting (OPs= 30.2%, CSP= 35.7%) activities. Other causes included marching (OPs= 9.0%, CSP= 7.0%), direct trauma (OPs= 5.0%, CSP= 0.0%), and landing (OPs= 12.0%, CSP= 0.0%), as seen in Figure 1. The most common activity being performed when a preventable injury occurred was physical training (OPs = 58.1% and CSP = 78.6%). In the OPs this was followed by the "other" category and tactical training (12%). The CSP reported tactical injuries as the next most common activity (15%).

The anatomical locations (Figure 2) most commonly injured were the leg (OPs = 50.0%, CSP = 64.0%), torso (OPs = 26.0%, CSP = 29.0%), and arm (OPs = 22.0%, CSP = 7.0%). The anatomical locations of preventable injuries are detailed in Table 2. The knee (OPs = 14.0%, CSP = 28.6%), back (OPs = 18.6%, CSP = 28.6%), and shoulder (OPs = 4.7%, CSP = 7.1%) are common locations for preventable injury among MARSOC personnel. The top three upper extremity sub-locations of injury were the shoulder/upper arm, wrist, and hand. The top three sub-locations for the lower extremity were the hip, knee, and lower leg.

All injuries were classified according to their onset as either acute or chronic. Of the 57 preventable injuries, 47 (82.5%) were defined as acute and 10 (17.5%) were defined as chronic. Operators sustained 36 (83.7%) acute injuries and 7 (16.3%) chronic injuries. The CSP sustained 11 (78.6%) acute injuries and 3 (21.4%) chronic injuries. On average, one preventable injury within this military population resulted in approximately 10 visits to a healthcare professional. No statistical difference was found between injury proportions of OPs and CSP.

Discussion

OPs and CSP work collectively to complete assigned missions; injury to either group can be detrimental to the operation and the rest of the Marine Special Operations Team. Understanding the injury characteristics present in these groups may allow for the development of population specific injury prevention interventions. The purpose of this study was to provide a descriptive analysis of injuries sustained in MARSOC personnel and compare injury characteristics between OPs and CSP. It was hypothesized that OPs and CSP would report different injury characteristics. This hypothesis was not supported by the findings of this study; conversely, findings suggest MARSOC OPs and CSP sustain similar injuries with similar mechanisms.

Injury Frequency and Incidence

This report reveals an injury incidence rate of 34.7 injuries per 100 person years for the total number of injuries sustained in MARSOC OPs and CSP. Individually, OPs incidence rates (37.3 injuries per 100 person-years) were slightly higher than that of the CSP (28.8 injuries per 100 person-years). The commonality of tactical and physical training endured may be reason for indifference in injury rates between groups. The lack of significant differences between the two groups may indicate a need to provide injury prevention strategies to both OPs and CSP.

The injury incidence rates discovered in this study are within similar range of incidence rates in previous studies.[4, 9, 10] Abt et al. studied injury epidemiology in U.S. Army Special Operations Forces using similar methods and found an injury incidence of 20.8 injuries per 100 subjects per year. Studies have reported 11 injuries per 100 subjects per year in military personnel, and conversely, others have reported up to 47 injuries per 100 subjects per year.[9,10] This higher incidence rate was reported in Marine Corps Special Warfare personnel at the time of a pre-deployment training cycle.[10] The differences in the injury rates reported in the literature may be related to time of data collection, training stages, or the difference in job requirements as injury risk and exposure may vary over the course of deployment evolutions.

Mechanism of Injury and Causes

As with previous military epidemiological studies, the majority of musculoskeletal injuries reported were preventable. The injuries reported occurred primarily during physical training (PT) in OPs (73%) and CSP (85%). Running was reported to be the most common activity performed at the time of the injury in both groups, followed by lifting. Ops reported a small number of injuries during marching, landing, or by direct trauma; whereas CSP reported even less or none within these categories. This difference could be due to different demands accompanied by different jobs. Although there were small percentage differences in the groups, no statistical differences were detected.

Similar to the results found in this study, the majority of injuries reported in the Naval Special Warfare and in the 101st Airborne Division (Air Assault) Soldiers were also sustained during PT.[4, 11] These studies found running to be the most common activity during which injury occurred. Conversely, Roy et al.[12] examined musculoskeletal injuries among an infantry brigade team deployed in Afghanistan, where the top five MOI were overuse (22%), reoccurring or exacerbations of pre-existing conditions (12%), lifting (8%), sports (8%), and traversing uneven terrain (7%). These differences may be related to the differences in job demands at the time of data collection or the definition of these activities. We did not separate weight lifting in the gym from other lifting activities outside of the gym, nor did we separate PT down to sport specific events. This study does not indicate any statistical differences in MOI or causes of injury in between OPs and CSP. This data stresses the importance of monitored training as the majority of preventable injuries were sustained during physical training versus organized tactical training.

Anatomical Location

Locations of injuries were compared between OPs and CSP in Figure 2. No significant differences between groups were seen in anatomical location. In this study, the leg, torso, and arm were the most common general anatomical sites of injury in MARSOC OPs and CSP. More specifically, the top three sublocations included the back, knee, and shoulder as anatomical sites that suffer injuries most often (Figures 3 and 4).[13] examined non-deployed, active duty service members, finding similar general anatomical sites with the vertebral column (40%) and lower extremity (39%) accounting for the majority of injuries followed by the upper extremity (14%). Different from this study, is the slightly higher incidence of vertebral column injuries and less injuries to the lower extremity.[13] examined a larger population of service members, whereas this study was a very specialized population of service members. Within similar studies, the lower extremity[4, 10] or back[9, 12] most frequently suffered injuries with the knee as the most common sublocation. Not all studies found the same order of prevalence in anatomic location, however, top sites were all of similar location.

Onset

Of all musculoskeletal injuries reported, 47 out of 57 injuries were classified as acute and 10 out of 57 were chronic. No statistical differences in injury onset were found between OPs and CSP. In accordance with similar research, the onset of musculoskeletal injuries is most often acute.[4, 5, 10] Unlike this study, other studies found that chronic or overuse injuries make up the majority of musculoskeletal injuries reported.[12, 14] Differences in findings from Linenger et al.[14]

and Roy et. al[15] could be related strictly to the population of interest, time of data collection, and definition of injury and window of time.

Limitations

This study is not without limitations. All collected data was retrospective and self-reported in the presence of a licensed clinician. With all self-reported data, memory recall may have an effect on the study findings. The sample population may be a limitation in that injury rates calculated are specific to MARSOC personnel. Not all specific military groups or MOS will sustain similar injuries or rates due to the specificity of job demands. Additionally, the small sample size led to low frequencies of reported injuries; however, findings were similar to previously reported injury incidence rates. The inability of obtaining a larger sample size comes from the study population being relatively small, as MARSOC is an elite group of U.S. Marines.

Conclusion

Similar injury incidence, injury proportions, and MOI have been identified in OPs and CSP. This study demonstrates the need to include CSP in injury prevention initiatives within the special operations community due to the similar injury profiles as OPs. This need to invest in the CSP just as in OPs is evident and should focus on reducing injury during PT activities. As the majority of injuries sustained are preventable injuries that occur during PT, implementation of prevention programs should be initiated. Specifically, monitoring activities with higher incidence rates such as running and lifting are of vital importance to maximize the effectiveness of a program. It is not uncommon for OPs or CSPs to participate in PT outside of command due to availability or personal interest, however, these methods of training do not ensure that safe or effective means of PT are taking place. OPs, regardless of branch of service, have access to highly qualified strength and conditioning personnel that have the training and opportunity to address injury risk factors during PT, provided they have enough scientific data to guide these interventions and adequate assessment tools. Supervision and correction of faulty mechanics through one on one supervision by trained strength and conditioning coaches or clinicians should be conducted regularly. Strength and conditioning personnel and medical commands should encourage further evaluation and utilization of their services for injury prevention and performance enhancing purposes.

Conflicts of Interest: The authors have no conflicts of interests to disclose

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Table 1. Injury Counts and Proportions

Types of Injury	**OP**		**CSP**		**Fishers Exact Test p-value**
Number of Subjects	153		66		
Total Injuries	57	37.25%	19	28.79%	1
Preventable Injuries	43	75.44%	14	73.68%	1
Physical Training Injuries	25	43.86%	11	57.89%	0.115
Tactical Training Injuries	5	8.77%	2	10.53%	1
Running Injuries	10	17.54%	7	36.84%	0.084
Lifting Injuries	13	22.81%	5	26.32%	0.739

*The proportion of preventable injuries was derived from “Total Injuries” and all other catergories were derived from “Preventable Injuries.”

Table 2. Injury Counts by Anatomical Location

Location	OP	CSP
Back	10	4
Shoulder/upper arm	7	1
Elbow	0	0
Forearm	0	0
Wrist	1	0
Hand	1	0
Hip	2	3
Thigh	3	0
Knee	5	4
Lower Leg	4	1
Ankle	4	0
Foot	3	1

Figure 1. Activities participating in when injury occurred

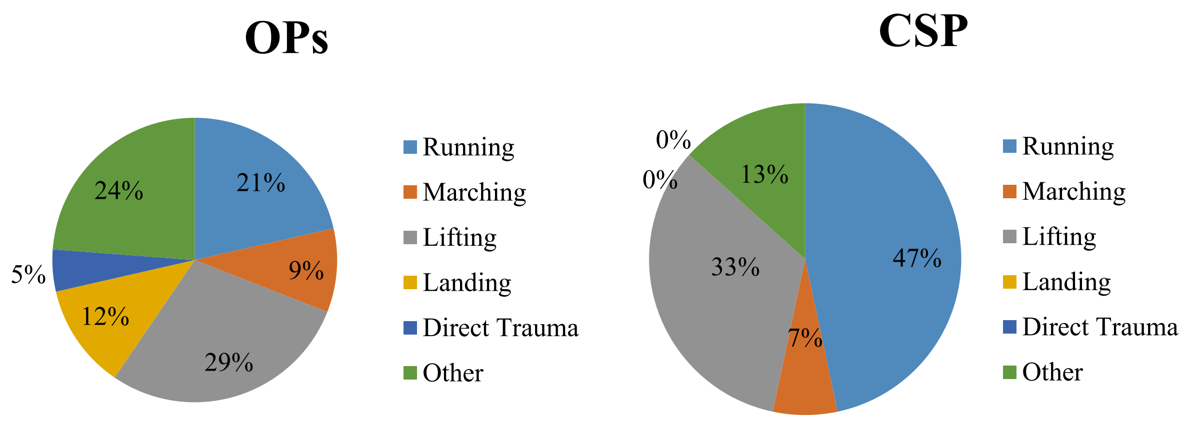


Figure 2. General Anatomical Locations of Injury

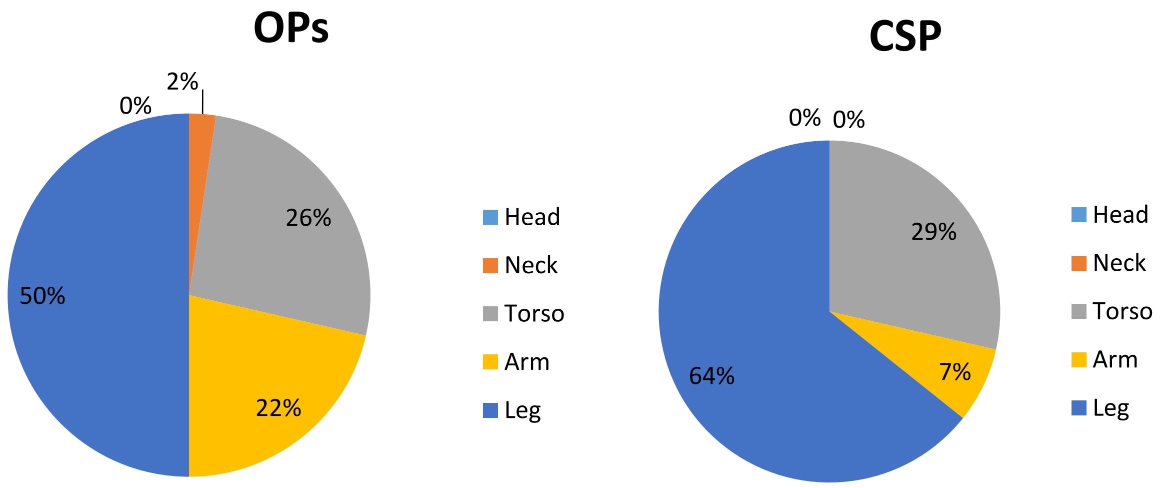


Figure 3. Upper Extermity Sublocations

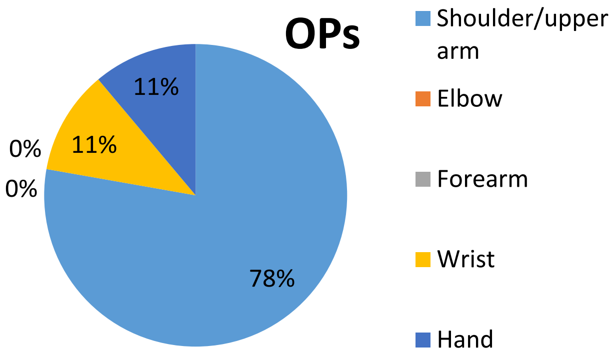
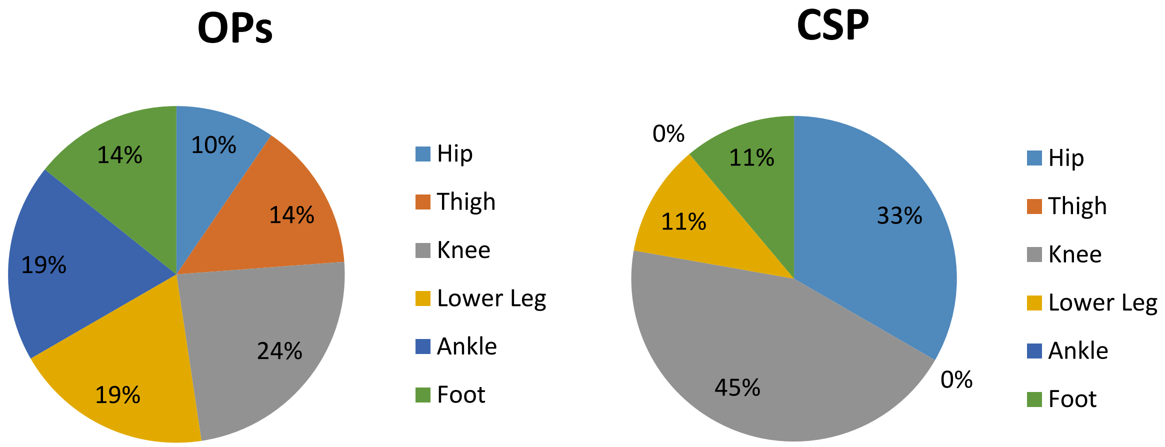


Figure 4. Lower Extremity Sublocations



Lifestyle Risk Factors in US Marines: Is There a Relationship to Injury and Performance?

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Abstract

Background: Lifestyle risk factors such as tobacco use, alcohol consumption, and too low or excessive body fat are known to contribute to overall health and wellness. Previous studies have indicated these lifestyle risk factors may be related to injury among service members. However, these issues have not been examined in the US Marine Special Forces. Therefore, the purpose of this study was to examine the relationship between lifestyle risk factors, musculoskeletal injury, and performance in Marines. **Methods**: Self-reported survey data was collected through a questionnaire completed by 414 Marines (26.5±4.4 years, 180.0±6.0 cm, 84.1±8.7 kg). Data collection occurred in a performance research laboratory environment during a functional testing session. Information collected included demographics, injury history, and lifestyle habits. Acute and chronic injuries were included if they occurred within the past year. Body fat percentage was measured using air displacement plethysmography. Logistic regression was performed to ascertain the effects of body fat percentage, alcohol consumption, and history or current use of tobacco on the likelihood that participants sustained an injury. Pearson correlations and ANOVAs were utilized to examine relationships between performance measures (strength, anaerobic power, and aerobic capacity) and lifestyle risk factors. **Results**: Of the 414 Marines in this study, 31.2% reported an injury in the past 12 months. The logistic regression model found tobacco use was associated with at least one injury in the past year ($\chi^2 = (1)\ 8.68$, $p = 0.003$). Anaerobic capacity and VO2max were found to be moderate and negatively associated with BF percentage. **Conclusions**: Although Marines are required to be physically and mentally fit due to the intense demands of the job, they are still affected by poor health related habits that may influence their health and performance. These findings may also provide supporting evidence to military leadership to further provide services that may improve these habits. **Word count**: 346

Introduction

Operational readiness is crucial to successful military activities. Musculoskeletal injuries and limited or low physical performance may be detrimental to individual preparedness, unit performance/safety, and overall mission readiness.[1,2] Furthermore, lost duty days by service members due to musculoskeletal injuries, and the medical care requirements associated with such injuries, place large medical and fiscal burden on the military.[2,3] In addition to combat and training loads, there are factors related to lifestyle that may contribute to the risk of musculoskeletal injury or low performance. These lifestyle factors may be modifiable and include tobacco use, alcohol consumption, and body composition.[4,5] Therefore, further examining the relationship between lifestyle factors and threats to individual preparedness is warranted to optimize military operations.

The negative health effects of tobacco use have been well documented and include an increased risk of cardiovascular disease, cancer, hypertension, and respiratory disease.[6, 7-11] In addition to these health risks, smoking is also associated with an increased risk of injury and reduced physical performance, all contributing to early discharge from the military.[7,12-14] Army recruits who smoked cigarettes were found to be 1.5 times more likely to sustain injury than non-smokers.[8] Additionally, smokers were found to perform worse on performance tests such as the two mile run, sit-ups, push-ups, timed hop test, functional movement screen, and the upper quadrant Y-balance test when compared to their non-smoking peers.[4] The use of smokeless tobacco in the military is also a growing concern as use of the product increases. In the 2011 DOD Health Related Behaviors Survey Executive Summary, nicotine use among Marines was reported to be the highest at 60.8% and smokeless tobacco use was reported at 19.8% for all military personnel, again with Marine use being the highest at 31.9%.[15] The use of tobacco and its effects on military personnel are also costly for the military, with tobacco-related illness or injury accounting for an estimated $564 million in medical expenses per year.[16] Given the high usage of tobacco products in the Marine Corps population and the previously established relationship between tobacco use and overall health, injury risk, and performance, the significance/risk of tobacco use needs to be understood in greater depth in this elite group.

Alcohol consumption may also be a concern for active duty military personnel, who have been shown to have higher drinking rates compared to civilians.[17,18] In 2006, approximately 1.9 million or 63% of those enrolled in the military healthcare system consumed alcohol.[16] Those that consumed alcohol ranged from light-to-moderate drinkers (31%) to infrequent binge drinkers (17%), to heavy drinkers (15%).[16] Aside from the general health concerns from consuming alcohol, drinking heavily and even acutely has been shown to increase injury risk.[19] Higher drinking rates have also been associated with high rates of noncombat-related hospitalizations and deaths.[17,20-22] The Marine Corps reported the highest prevalence of binge drinking at 56.7% and greater number of days where alcohol was consumed compared to other military branches.[15] The cost of alcohol related treatments, including accidents and detoxifications, was estimated to be $425 million in the same year.[16] Unknown, however, is if these statistics hold true for Marine Special Forces. Research on alcohol consumption and its relationship to injury and performance is more limited compared with other lifestyle risk factors.

Excess body fat negatively affects health across the United States,[23] including a reported 15% increased risk of injury in overweight adults.[24] Military personnel are not immune to this trend.[5,15] Similar to the general population, a greater body mass index (BMI) has been associated with an increased risk of injury in military personnel.[25] The consequences of this interaction cost the military healthcare system approximately $1.1 billion annually.[16] Those with a greater BMI may also perform at lower levels than their counterparts. A study by Teyhen et al. found that military personnel with a BMI of 27.5 kg/m^2 or greater, performed worse on performance tests including the 2-mile run, triple crossover hop, 6-m timed hop test, and sit-up test.[4] Although BMI has been studied in great detail within military populations, measures such as fat and fat free mass index, may more accurately represent body composition in this population. For example, strength and aerobic measures have been reported to be adversely affected by higher body fat percentages.[26,27] Crawford et al. discovered that Army soldiers with a greater body fat (BF) percentage and fat mass show a decline in physical performance.[26] Body fat percentage provides more information on body composition than BMI, however, there is a lack of research on how BF percentage relates to injury and performance measures in Marines.

Although previous studies suggest that such lifestyle risk factors may contribute to greater likelihood of injury and reduced performance, research has yet to examine these issues in United States Marine Corps Forces Special Operations Command (MARSOC) personnel. Previous research has studied recruits in boot camp settings and military in other branches, this unique group of Marines poses different challenges as high intensity training varies in high risk environments. Therefore, the purpose of this study is twofold; 1) to examine the relationship between self-reported lifestyle risk factors and musculoskeletal injury and 2) to examine the relationship between self-reported lifestyle risk factors and physical performance measures in MARSOC personnel. We hypothesize that there will be a significant, positive association between alcohol consumption, body fat percentage, and tobacco use and injury. In addition, we hypothesize a significant, negative relationship exists between alcohol consumption, body fat percentage, tobacco use and physical performance. Determining the relationship between such lifestyle factors to injury and performance will help clinicians and leaders better construct interventions to optimize the health, wellness, and performance of US Marines.

Methods

Participants

Participants were Marines enrolled in a larger on-going research study. Enrollment occurred from April 2015 to November 2017. Inclusion criteria included clearance for full and unrestricted participation in physical and tactical training, and free of injury to arms, legs, back, and neck within the past month that led to training cessation or medical treatment. The university's Institutional Review Board approved all research procedures and written informed consent was obtained from each subject prior to participation in the study.

Procedures

Data collection was completed in a laboratory setting, with no military supervisors involved. Participants were ensured all protocols were voluntary prior to beginning testing session.

Patient-Reported Questionnaire

All participants were interviewed by a researcher regarding their lifestyle habits and musculoskeletal injuries. Lifestyle characteristics and habits of interest included tobacco use and alcohol consumption. Tobacco use was defined as use of cigarettes, cigars, or smokeless tobacco regularly at a minimum of once per month. Tobacco use was not recorded if the participant reported only social use equating to once or twice a year. Tobacco use was broken down two ways: 1) as a dichotomous variable: current use or history of use and never used, and 2) into four categories: current user, ex-user < 12 months, ex-user >12 months, and never used. An ex-user < 12 months was defined as a participant who quit smoking less than 12 months ago. An ex-user > 12 months was defined as a participant who quit smoking more than 12 months ago. Typical servings of alcohol per week during the previous 3 months were recorded. One serving of alcohol was defined as 5 ounces of wine, 12 ounces of beer or 1.5 ounces of distilled spirits. Alcohol use was reported as the average servings of alcohol consumed each week.

Injuries that occurred within the last year were recorded. The definition of an injury, as previously described by Heebner et al.,[28] was used in this study:

> *An injury was defined as an injury to the musculoskeletal system (bones, ligaments, muscles, tendons, etc.) that caused the participant to stop or modify training or physical activity for at least one day, regardless if medical attention was sought. Injuries included conditions such as sprains, strains, labral tears, and fractures but not contusions or lacerations.*

Data collected were entered directly into a customized online survey application (REDCap electronic data capture tools hosted at University of XXXXXX[29]) during each interview.

Laboratory and Performance Testing

Body Composition

Height was taken barefoot using a wall stadiometer (Doran Scales, Inc, Batavia, IL). Body fat percentage was determined using the Bod Pod Body Composition System (Cosmed, Chicago, IL). This system utilizes air displacement plethysmography to measure body volume and calculate body density. Participants wore only a swim cap and spandex shorts during testing. The test provided participants fat mass and fat-free mass in kilograms. Fat mass index (FMI) and fat-free mass index (FFMI) were then calculated from fat mass and fat-free mass Bod Pod measurements and height measurements (FMI = fat mass [kg]/height [m^2]; FFMI = fat free mass [kg]/height [m^2]). FMI and FFMI are height-normalized indices of body composition.[30] Intrasubject reliability has demonstrated an ICC of 0.98 and standard error of measurement (SEM) of 0.47% body fat.[26]

Aerobic Capacity

Maximal oxygen uptake (VO_2max; ml/kg/s) was measured during a modified Astrand treadmill protocol to volitional exhaustion using a metabolic gas analyzer (TrueOne 2400, ParvoMedics, Sandy, UT). The treadmill protocol was based on a variation of the protocol designed by Astrand. [31] Heart rate data were collected with a heart rate monitor (Polar USA, Lake Success, NY). The speed for the test was selected according to the subject's most recent self-reported three mile run time, and incline was increased 2% every three minutes until volitional exhaustion. This protocol has been previously used and found to be reliable when maximal effort is put forth by the participant.[30,32]

Anaerobic Power

Anaerobic power was measured using a Wingate cycling test on the Velotron cycling ergometer (RacerMate, Inc, Seattle, WA).[33] This 30-second maximal effort test has shown to be reliable and valid.[34] Test set-up is standardized and has been described elsewhere.[26] Seat and handlebar position were adjusted to ensure a comfortable position and 10-15 degrees of knee flexion when the bottom of the peddle struck. Following a five-minute warm up (125W), subjects completed a 30-second Wingate protocol (9.0% body weight braking torque). Subjects were instructed to pedal as hard and as fast as they could against the applied resistance for the length of the test, all while maintaining a seated position and front handgrip position. Verbal encouragement was provided by the investigators. Anaerobic power (AP) and anaerobic capacity (AC) were analyzed relative to body weight (W/kg).

Musculoskeletal Strength

Isokinetic trunk flexion/ extension, and bilateral shoulder internal/ external rotation, and knee flexion/extension strength was assessed using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc, Shirley, NY). Isokinetic strength testing has been demonstrated to be reliable with ICC values ranging from 0.74 – 0.99.[26,35] Prior to testing, participants were properly fit to the chair using standardized procedures, varying depending on the segment being tested.[26,28] Each participant had the opportunity for warm-up trials at 50% of their maximal effort and one familiarization trial at 100% effort. All contractions were concentric-concentric at 60 degrees/second. Strength, using average peak torque, was determined by the average of five repetitions and was analyzed relative to percent body weight.

Statistical Analysis

Descriptive statistics were calculated for age, height, weight, BF percentage, FM, FFM, years of service, injury history, tobacco, and alcohol use. The relationship between modifiable lifestyle risk factors and injury within the last year was examined by constructing logistic regression models for each dependent variables using a backwards step-wise method. Pearson correlations were completed to determine if variables were related prior to adding to a multivariate regression model. Tobacco use was entered as a dichotomous and a categorical variable, and age, alcohol, BF percentage, FMI, and FFMI as continuous variables. Multiple models were run to determine best fit.

The relationship between modifiable lifestyle risk factors (age, alcohol consumption, and BF percentage) and performance measures were individually analyzed using Pearson coefficient correlations. A one-way analysis of variance (ANOVA) analyzed the differences between performance measures and tobacco usage by the four categories. To determine where differences occurred, a Fisher's LSD post-hoc test was utilized due to smaller sample sizes once broken down into groups. An a priori alpha level of 0.05 was set prior to denote statistical significance for comparison. Statistical analyses were performed using IBM SPSS Statistics Version 24 (IBM Corp, Armonk, NY).

Results

Descriptive Statistics

Demographic data for the 414 male, MARSOC personnel in this study are presented in Table 1. Of the 414 participants, 31.2% reported having an injury in the past 12 months. The breakdown of tobacco use is displayed in Table 2 with 5%, 2%, and 29.2% of MARSOC personnel currently using cigarettes, cigars, or smokeless tobacco respectively. Current alcohol usage was reported by 75% (300/396) of Marines, averaging 3.5 servings per week.

Injury Prediction Modeling

Pearson correlations revealed BF percentage and FMI are significantly and highly correlated ($r = 0.98$), therefore only BF percentage was entered into the multivariate logistic regression models. Logistic regression models were constructed with injury from the last year as the dependent variable. Multivariate logistic regression models tested with each tobacco type (cigarettes, cigars, and smokeless) and their four categories (current user, ex-user < 12 months, ex-user >12 months, and never used) separately with age, BF percentage, and alcohol use were analyzed finding no variable contributed significantly to the model. A final model was run with tobacco use as a dichotomous variable (history of any use of tobacco- yes/no), age, BF percentage, and alcohol use. The final model was significant with tobacco use as the only contributing variable (χ^2 = (1) 8.68, p = 0.003, Exp(B) = 2.08) increasing the risk of injury. See Table 3 for the logistic regression coefficients, significance values, and odds ratios.

Laboratory and Performance Testing

Laboratory and performance data are summarized in Table 4. Weak to moderate, negative correlation was found between age and AC (r = -0.34, $p < 0.001$), VO_2max (r = -0.43, $p < 0.001$), knee flexion (r = -0.18, $p < 0.001$) and extension strength (r = -0.11, p = 0.03).

BF percentage had significant weak negative correlations with knee flexion strength (r = -0.34, $p < 0.001$) and a moderate negative correlation with AC (r = -0.43, $p < 0.001$), and VO_2max (r = -0.58, $p < 0.001$). Weak positive relationships were found between FFMI and AP (r = 0.41, $p < 0.001$), AC (r = 0.16, p = 0.004), trunk flexion (r = 0.16, p = 0.003) and trunk extension strength (r=0.14, p = 0.01). Significant negative relationships were found between FMI and AC (r = -0.43, $p < 0.001$), VO_2 max (r = -0.63, $p < 0.001$), shoulder IR (r = -0.24, $p < 0.001$) and ER strength (r = -0.14, p = 0.01), knee flexion (r = -0.35, $p < 0.001$) and extension strength (r = -0.24, $p < 0.001$), and trunk flexion (r = -0.12, p = 0.03) and extension strength (r = -0.14, p = 0.01).

Results of a one-way ANOVA indicated no differences were identified in strength or AP measures based on the various categories of cigarette ($p > 0.13$), cigar ($p > 0.38$), or smokeless tobacco use ($p > 0.66$). Significant differences were identified for smokeless tobacco users between groups in AC (p = 0.03) and VO_2max (p = 0.05, Table 5). Post hoc analyses revealed

AC was significantly greater in those who have never used smokeless tobacco and current users (p = 0.04, Cohen's d = 0.26), current users were significantly weaker than ex users <12 months (p = 0.03, Cohen's d = 1.22), and ex users <12 months were stronger than ex users of >12 months (p = 0.04, Cohen's d = 1.55). Post hoc analysis revealed VO_2max was significantly different between those who have never smoked and ex users >12 months (p = 0.03, Cohen's d = 0.88), and current users and ex users of >12 months (p = 0.02, Cohen's d = 1.06).

Discussion

This study aimed to determine if relationships exist between lifestyle risk factors, injury, and performance in MARSOC personnel. We hypothesized that increased tobacco use, alcohol consumption, and body fat percentage would increase the probability of a Marine sustaining an injury in the previous 12 months. The authors also hypothesized that increased tobacco use, alcohol consumption, and body fat percentage would be associated with poorer physical performance. Despite their overall high levels of physical fitness, MARSOC personnel are still affected by lifestyle risk factors or choices which may place them at an increased risk for musculoskeletal injuries and decreased performance, particularly with tobacco use.

The findings of this study indicate a relationship between musculoskeletal injury and history or current use of tobacco within our logistical regression model, however, no relationships were found when tobacco use was broken down into categories. We attribute the lack of relationship between injury and tobacco use categories to the small sample of our population once stratified into groups. Like the findings of our logistical regression model, the Army has found during basic training, cigarette smoking alone significantly increased the risk of musculoskeletal injury.[8,9,38] Recruits and soldiers that reported a history of smoking were at greater odds (OR=1.34-1.5), of sustaining an injury than those without a history of smoking.[5,8]

Additionally, a systematic review on cigarette smoking's impact on lower extremity musculoskeletal injuries during military training revealed smoking to be a moderate risk factor for overuse injuries with a 37% greater risk than for nonsmokers.[39] As a whole, 30.8% of Marines report cigarette use [15] whereas only 5% of our sample of MARSOC personnel indicated current usage.

Tobacco usage among the subjects in this study may be directly related to the high performance standards that accompany special operations. Hermes et al. found those service members, in all branches of the military, that deploy and are exposed to combat are at an increased risk of smokeless tobacco initiation and persistence.[40] Current smokeless tobacco use was reported by 29.2% of our sample. Although not found to be related to injury, the use of smokeless tobacco may have a determental effect on some performance measures. This study was able to detect significant differences in AC and VO_2max measures between those who have never or currently use smokeless tobacco and those who were past users. This may lead us to attribute a decrease in performance to use of smokeless tobacco, however, with our past history of usage categories being small (n = 18/373), it is difficult to say if these results are clinically meaningful. As smokeless tobacco has shown to be more prevalent[15] and potentially related to decreased performance in this population, education and cessation programs should include not only long term health consequences but also the influence it may have on performance.

According to Marine age standards (18-25 years = 18% BF; 26-35 years = 19% BF; 36+ years = 20% BF) set by the Department of Defense, 21.8% of our participants did not meet their age-based BF percentage requirement.[36] Another common risk factor for injury is high BMI or BF percentage.[5,41,42] This study examined BF percentage in relation to injury and found no association between these variables and injury. However, consistent with previous literature,[26,43] our results indicated that AP and AC, as well as some strength measures, were hindered as BF percentage increased. Crawford et al. compared fitness test results of those with greater than 18% BF to those below this threshold, finding that those with less than 18% BF performed better on 7 out of 10 fitness tests than those with greater BF percentage.[26] In our cohort, the moderate relationship detected between BF percentage and AP, VO_2 max, and strength indicates that as fat mass increased performance measures decreased. Other research has found similar findings, as leaner military personnel performed better in anaerobic tasks lasting for longer periods of time and as BF increased there was decreased AC.[26] The extra weight carriage that is not responsible for performance of a specific task will incur a performance deficit. [26,44] Performance specialists and clinicians working with this population should be aware of the detriment that a higher BF percentage may have on injury and performance. Exercise and dietary needs should be addressed to overcome higher BF percentage.

This study did not indicate any relationship between alcohol consumption and injury or performance, although 77% of our sample consumes on average 3.5 servings of alcohol each week. Current use among all service members has been reported to be slightly higher at 84.5% as reported by the 2011 DOD Health Related Behaviors Survey Executive Summary.[15] This difference may be due to the elite group of Marines within this study, as they are also slightly older as a whole. Additionally, this study considers a self-reported average over a typical week and not during specific periods of training that could account for differences in consumption reports. Overall, research investigating alcohol consumption and its relationship to injury and performance in the military is limited and should be studied in greater detail.

This study does have limitations. As data were collected retrospectively, memory recall may influence our findings. In attempts to reduce poor memory recall, we only included injuries that occurred within 12 months of study enrollment. Additionally, injury history and lifestyle data were self-reported, however, a trained clinician assisted with injury reporting details. As mentioned elsewhere,[5] this could be a strength when it comes to injury data as military personnel may not seek care for all injuries sustained providing a more complete perspective. However, if these individuals fear any reports of substance (tobacco or alcohol) use to their command, they may be hesitant to report accurate information despite the assurance their information was confidential resulting in reporting bias. Lastly, the average BF percentage (14.9%) of this sample is relatively low, which may lead to limited findings. A greater dispersion in BF percentage values may have resulted in a different relationship with injury.

As musculoskeletal injuries continue to be a burden on our service members, it is imperative that we continue to identify risk factors that may contribute to these injuries and, just as important, low performance. The findings of this study may indicate that early education to never start use of tobacco is extremely important. Our results provide additional evidence to military leadership to further support services that assist service members in reducing poor lifestyle habits. Strength and conditioning coaches should be aware of the effects of these lifestyle risk factors and provide education and backing to military personnel who indulge in such habits. When clinicians develop prevention or rehabilitation programs, it is important to consider these lifestyle risk factors for patient education, prognosis, recovery, and long-term quality of life.

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Table 1. Participant Demographics

Demographic	**Mean**	**SD**
Age (years)	26.5	4.4
Height (cm)	180	6.0
Weight (kilograms)	84.1	8.7
BF percentage	14.9	5.4
Fat mass (kilograms)	12.7	5.4
Lean mass (kilograms)	71.6	7.2
Years of service	6.4	4.1

Table 2. Tobacco Frequency and Percentage

	Cigarettes	**Cigars**	**Smokeless Tobacco**
Currently use	19 (5)	8 (2)	109 (29.2)
Ex-user < 12 months	22 (5.5)	1(0.3)	9 (2.4)
Ex-user > 12 months	81 (20)	4 (1)	9 (2.4)
Never used	280 (69.5)	382 (96.7)	246 (66)
Total reported	402	395	373

Table 3. Final Multivariate Injury Regression Model

	B	**SE**	**p-value**	**Odds Ratio**
Age	-0.023	0.029	0.429	0.978
Alcohol consumption	0.021	0.031	0.498	1.021
BF percentage	0.012	0.024	0.603	1.013
History of tobacco use	0.732	0.249	0.003	2.080

Table 4. Correlations between lifestyle risk factors and performance measures

	Anaerobic power	Anaerobic capacity	VO_2 Max	Shoulder IR	Shoulder ER	Knee Flexion	Knee Extension	Trunk Flexion	Trunk Extension
Age	0.070	**-0.336***	**-0.429***	-0.075	0.029	**-0.182****	**-0.110***	-0.013	-0.022
Alcohol consumption	0.030	-0.008	**-0.145***	**-0.144****	0.005	-0.050	-0.075	0.060	0.038
BF percentage	-0.020	**-0.433***	**-0.579***	**-0.244****	**-0.140***	**-0.343****	**-0.233****	**-0.129***	**-0.154****

*Correlation is significant at the 0.05 level (two tailed)

**Correlation is significant at the 0.01 level (two tailed)

Table 5. ANOVA results to determine if differences exist between smokeless tobacco use categories (means and standard deviation)

Type	Anaerobic power	Anaerobic capacity*	VO_2 Max*	Shoulder IR	Shoulder ER	Knee Flexion	Knee Extension	Trunk Flexion	Trunk Extension
Never used	12.7 ± 0.63	9.2 ± 0.78	53.8 ± 4.9	0.65 ± 0.14	0.42 ± 0.06	1.41 ± 0.24	2.60 ± 0.44	2.37 ± 0.44	4.08 ± 0.76
Current user	12.8 ± 0.63	9.0 ± 0.76	53.1 ± 4.7	0.68 ± 0.12	0.43 ± 0.05	1.40 ± 0.22	2.60 ± 0.40	2.40 ± 0.41	4.15 ± 0.79
Ex user < 12 months	12.8 ± 0.56	9.7 ± 0.28	56.3 ± 3.3	0.63 ± 0.08	0.42 ± 0.06	1.40 ± 0.17	2.60 ± 0.28	2.50 ± 0.55	4.17 ± 0.44
Ex user > 12 months	12.7 ± 0.63	8.8 ± 0.77	58.1 ± 4.9	0.65 ± 0.14	0.42 ± 0.06	1.50 ± 0.17	2.60 ± 0.37	2.30 ± 0.55	4.18 ± 0.77

*Significant at the 0.05 level (two tailed)