Journal of Science and Medicine in Sport 22 (2019) 494–499

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Fight load index and body composition are most associated with combat fitness in female Marines

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ARTICLE INFO

Article history:
Received 28 June 2018
Received in revised form 25 October 2018
Accepted 29 October 2018
Available online 6 November 2018

Keywords:
Military fitness
Body composition
Fat-free mass
Cluster modeling
Women in combat

ABSTRACT

Optimizing tactical fitness is important for combat readiness and injury prevention, especially as women have entered ground combat military occupational specialties.

Objectives: To assess characteristics of male and female Marines by Combat Fitness Test (CFT) performance clusters.

Design: Cross-sectional study.

Methods: Anthropometric, body composition (BF%, fat and fat-free mass [FM and FFM], and Fight load index [FLI], physiological (maximal oxygen uptake, lactate threshold and anaerobic power/capacity), and musculoskeletal (isokinetic strength of the knee, shoulder, torso, and isometric strength of the ankle) assessments were obtained from 294 male (M) and female (F) Marines. Hierarchical cluster analysis classified Marines based on performance of two CFT events (sec): Maneuver Under Fire (MANUF) and Movement to Contact (MTC). Following tests for normality, one-way ANOVA or Kruskal Wallis tests, followed by Bonferroni post-hoc tests, assessed characteristics across clusters and sex (alpha = 0.05).

Results: Two clusters (C) were determined: C1: N = 66F, 16M and C2: N = 18F, 194M, with C2 demonstrating better performance on the MANUF and MTC. C1F demonstrated significantly greater BF% and FLI than C1M, C2F, and C2M. C2M demonstrated significantly greater knee flexion strength than C1F and C2F, but C1M was only significantly greater than C1F. C2M demonstrated significantly greater ankle eversion and inversion strength than C1F.

Conclusions: Women with increased BF%, increased FM and reduced FFM relative to a fighting load may have decreased performance in combat-related tasks. Training programs based on an individual Marine's baseline body composition and fitness characteristics can enhance combat fitness and force readiness.

Practical implications

- Women with increased body fat percentage and increased fat mass and reduced fat-free mass relative to a fighting load may have decreased performance in combat-related tasks.
- Training programs based on an individual Marine's baseline body composition and fitness characteristics can enhance combat fitness and force readiness.
- Both male and female Marines should focus on training to optimize modifiable physiological and musculoskeletal characteristics, such as body composition, aerobic/anaerobic fitness, and muscular strength/power, to reduce performance gaps between sex.

1. Introduction

In January 2013, then-United States Secretary of Defense (SECDEF), Leon Panetta, rescinded the 1994 Direct Ground Combat Definition and Assignment Rule (DGCDAR) that excluded women from assignment to specialties and units whose primary mission was to engage in direct combat on the ground. The SECDEF allowed the Services to research the impact of integration to inform successful policy implementation and offered the Service Chiefs an opportunity to request an exception to the policy if research

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https://doi.org/10.1016/j.jsams.2018.10.014
1440-2440/

suggested it was warranted. On 3 December 2015, the SECDEF announced that beginning in January 2016, all specialties and units will be open to women, without exception (Fragmentary Order 4 (Implementation) to Marine Corps Force Integration Campaign Plan). As such, further research is warranted in order to determine strategies to optimize combat-relevant performance and minimize risk of injury relative to female integration into these previously restricted roles.

The 2014 Department of Defense *Women in Combat Symposium* summarized implications of women openly serving in direct ground combat, including inherent sex differences in physical characteristics, physiological characteristics, and musculoskeletal injury profiles and physical demands of combat MOSs.[1] Physically demanding combat jobs require adequate strength (especially upper-body), power, endurance, mobility, and flexibility.[2] During an International Military Physiology Roundtable as part of the 3rd International Congress on Soldiers' Physical Performance, aerobic fitness and strength were noted as essential components of health- and performance-related physical fitness; additionally, strength, power, and local muscular endurance were described as critical fitness characteristics for each MOS.[3] Also noted was that military personnel of smaller stature, particularly women, are at a disadvantage during military activities where an absolute load must be carried, as they would be required to work at a greater percentage of their maximal capacity.[3] On average, female military personnel possess significantly less upper- and lower-body strength and power, less fat free tissue, and decreased aerobic and anaerobic capacity, while demonstrating more favorable static postural stability and flexibility compared to their male counterparts. However, men and women demonstrate an overlap in physiological and musculoskeletal capabilities, indicating that the strongest and fittest women may outperform some men.[4] A recent US Army study examined sex and age differences between male and female operational Soldiers and those in Basic Combat Training (BCT), and found that sex differences in cardiorespiratory and muscular fitness were more prominent between men and women in BCT.[5] Authors discussed that while women enter BCT less fit than their male counterparts, that previous research has demonstrated that women may increase fitness at twice the rate of men following BCT, which narrows the sex gap among modifiable physiological and musculoskeletal characteristics.[1,5,6] As women are now enlisting in previously-restricted MOS, it is important to identify physical, physiological, and musculoskeletal characteristics of female and male Marines demonstrating high performance during combat-related tasks in order to both identify characteristics of women with enhanced combat-related performance as well as to inform training programs to optimize combat-relevant fitness in women.

In response to the repeal of DGCDAR, the United States Marine Corps (USMC) assessed more than 35 studies and established the Ground Combat Element Integrated Task Force (GCE ITF) to study potential impact of gender integration in ground combat MOS(s) and units newly opened to female Marines. As part of this research, the University of Pittsburgh examined a comprehensive battery of physical, physiological, and musculoskeletal characteristics as Marine volunteers entered the GCE ITF and tracked injuries through the duration of the research effort.[7] Among these characteristics was calculation of a Fight load index (FLI), which take into consideration fat mass and a typical fight load relative to fat free mass (FM) expressed as an index. Similar "Dead Mass Ratio" indices have been utilized in military populations to predict military task performance.[8] These ratios were developed because lean body mass is positively correlated with load-carriage performance[9] whereas body fat has been negatively correlated with load-carriage performance,[10] so additional external load carriage as "dead mass" would intuitively further negatively affect performance. Lyons et al. demonstrated that maximal oxygen uptake and a lean body mass to dead mass ratio were most closely associated with percent VO_2max and cardiovascular demands of heavy (40 kg) load-carriage tasks.[11]

The overall goal of the GCE ITF research aim was to identify physiological and musculoskeletal predictors of success in ground combat arms. This research demonstrated that a greater proportion of female Marines (40.5%) sustained at least one musculoskeletal injury compared to male Marines (18.9%),[7] which parallels recent research examining risk factors for injury during Army Basic Combat Training (BCT) (39% of men and 61% of women sustained at least one injury during BCT).[12] Additionally, results indicated that aerobic capacity and upper body strength may be associated with risk of sustaining a musculoskeletal injury among male and female Marines.[7] However, further analyses are warranted to determine the characteristics most associated with success in combat-relevant tasks.

The USMC Combat Fitness Test (CFT) identifies individualized, quantifiable, and objective measures of performance during combat-relevant tasks.[13] The components of the CFT include a 30 pound ammo can lift, an 880-yard "Movement to Contact" run while wearing boots and utility trousers, as well as a "Maneuver Under Fire" drill that assesses ability to sprint, crawl, evacuate a casualty using two carry techniques, throw a hand grenade, complete pushups, and carry ammo cans. By quantifying cumulative performance across components of the CFT, we may be able to characterize male and female Marines with superior performance on combat-relevant tasks. To accomplish this, a cluster analysis, was utilized to determine characteristics of Marines with similar CFT performance.[14] From this analysis, participants with similar metrics are grouped together into distinguishable clusters, resulting in distinct groups of Marines with similar performance across CFT components. If noticeable trends of physical, physiological, and musculoskeletal characteristics can be determined among and between clusters, these data may be useful in determining the most important factors determining combat-relevant fitness.

2. Methods

Male Marines (N = 218, age: 22.4 ± 2.6 years, height: 174.5 ± 8.0 cm, mass: 80.7 ± 10.6 kg) and female Marines (N = 84, age: 22.6 ± 2.8 years, height: 163.7 ± 5.3 cm, mass: 64.3 ± 7.1 kg) who volunteered and were selected for participation in the USMC GCE ITF were eligible to participate. Inclusion criteria for the study included: (1) Marines up to age 55 years and (2) currently cleared for full active duty participation by the Senior Medical Officer or designated member of medical staff. Exclusion criteria include: (1) participants with complaints of current symptomatology of extremities, neck, or back preventing training within the previous three months, (2) allergy to adhesive products, and, if female, (3) knowingly pregnant. Development of any disease or condition prohibiting active participation in Marine training automatically excluded participants.

Upon checking into the GCE ITF, male and female Marines attended a recruiting brief and provided written informed consent for participation in the University of Pittsburgh research study if he/she chose to participate. Volunteers were tested at the University of Pittsburgh Warrior Human Performance Research Center, and underwent a two-day battery of laboratory and field testing at baseline (GCE ITF check-in). Testing began first thing in the morning and the test order was designed so the highest intensity tests were performed later in the testing battery, and tests of maximal effort were performed last and on separate days. Each subject participated in a standard warmup and familiarization procedure prior to undergoing each test. USMC Physical Fitness Test (PFT) and Combat Fitness Test (CFT) data were collected from the Marine's most recently completed test. All study procedures were approved by the University's Human Research Protection Office.

Body composition was measured via air displacement plethysmography with the Bod Pod Body Composition System (Cosmed, Chicago, IL) using standard procedures. Air displacement plethysmography is a reliable (Intraclass Correlation Coefficient (ICC) = 0.98),[15] precise (Standard Error of the Mean (SEM) = 0.47% BF),[15] and a criteria-valid[16] measure. Percent body fat (BF%), fat mass (FM: kg), and fat free mass (FFM: kg) were recorded, and FLI was calculated using the following equation [(fight load of 36.8 kg + FM)/FFM], similar to previously utilized indices.[8]

Anaerobic power and capacity were measured during an anaerobic power test (Wingate test) using an electronically-braked Velotron cycling ergometer (RacerMate, Inc., Seattle, WA). The Wingate anaerobic cycle test is a highly reliable and valid measure of lower-extremity anaerobic power and capacity.[17] The absolute (W) highest power output (anaerobic power (A P)) observed during the first 5 s and average power output (anaerobic capacity (AC)) over the 30 s of exercise were recorded.

Aerobic capacity was measured utilizing a stationary metabolic system (TrueOne2400, ParvoMedics, Sandy, UT) during a laboratory-based treadmill (WOODWAY USA, Inc., Waukesha, WI) maximal oxygen uptake (VO_2max) test. Participants were tested according to a standardized protocol previously reported.[18,19] The maximal oxygen uptake test measured with breath-by-breath analysis is a highly reliable,[20] precise (SEM = 3%),[21] and criteria-valid[20] measure. Both absolute (ml/min) and normalized (ml/kg/min) VO_2max were recorded. Lactate threshold (LT) was blood lactate was assessed with a portable lactate analyzer (Lactate Pro®, Arkray, Inc, Kyoto Japan). The Lactate Pro® has demonstrated reliability at different lactate concentrations (coefficient of variation between 2.8 and 5.0%). Procedures have been previously described.[22]

Shoulder internal/external rotation, torso rotation, and knee flexion/extension isokinetic strength were collected using the Biodex Multi-Joint System 3 Pro (Biodex Medical Systems, Inc., Shirley, NY) utilizing previously reported procedures.[19] This instrumentation has been found to be precise and reliable for position (SEM): 0.45–0.60°, (ICC) > 0.99) and torque (SEM: 0.00–0.39Nm, ICC > 0.99).[23] Isometric ankle eversion/inversion strength was assessed using a hand-held dynamometer (Lafayette Instruments, Lafayette IN) utilizing previously reported procedures.[4] Hand-held dynamometry has been previously reported to have excellent intrarater (ICC(3,1) = 0.78–0.94) and interrater (ICC(3,1) = 0.77–0.88) reliability and is a valid measure of ankle strength.[24,25] For isokinetic and isometric strength tests, peak torque (Nm) and peak force (kg) were averaged across trials.

Data were utilized from the participants' most recently completed CFT. Tests utilized for analysis include Movement to Contact (MTC: sec), and Maneuver Under Fire (MANUF: sec). CFT procedures have been described previously[13] Ammo can lift was not utilized, as this event score is capped at a maximal achievable score and would not provide an appropriate continuous dataset for the clustering analysis.

Cluster analysis (CA) is a widely-used data mining approach identifying groups of participants or entities with similar features.[26] It recently has been applied successfully in Sports Medicine to characterize elite and sub-elite athletic performance[14] and determine different weight transfer styles in the golf swing.[27] To classify Marines based on performance of two CFT events (sec): MANUF (Mean: 157.8, standard deviation (SD): 27.0) and MTC (Mean: 184.2, SD: 20.9), an agglomerative Hierarchical cluster analysis (HCA) was performed. The HCA is one of the popular cluster methods and it aims to build a hierarchy of clusters.[26] The agglomerative HCA builds clusters from bottom to up. It starts with each subject as its own cluster and at each step, merges the closest clusters based on the distance metric and the linkage criteria until only one cluster remains. The cluster structure is displayed as a tree-like diagram, named dendrogram (Fig. 1).

The distance metric measures the distance between pairs of participants and the Euclidean distance was chosen. For example, for subject a: ($MANUF_1$, MTC_1) and subject b: ($MANUF_2$, MTC_2), $dist(a, b) = \sqrt{(MANUF_1 - MANUF_2)^2 + (MTC_1 - MTC_2)^2}$. The linkage criteria specifies the distance between clusters of the participants. The average linkage was applied and the distance $D_{i,j}$ between cluster C_i and C_j is assigned to be the mean of the distance between the pairs of participants a and b, where $a \in C_i$ and $b \in C_j$. Since two CFT events carry the same unit (sec), the HCA was carried out on the data without standardization and the computation was performed using *dist* (distance matrix computation), *hclust* (hierarchical cluster analysis) and *cutree* (clusters selection) functions in R.[28] Once clusters were established, following tests for normality, one-way ANOVA or Kruskal Wallis tests, followed by Bonferroni post-hoc tests were used to assess characteristics across clusters and sex (alpha = 0.05, two-sided).

3. Results

As shown in Fig. 1, two clusters (C) were determined: C1: N = 66F, 16M and C2: N = 18F, 194M), with C2 demonstrating better performance on the MANUF and MTC (Fig. 2).

Physical, physiological, and musculoskeletal strength characteristics were compared among both performance clusters and stratified by sex (Table 1). C1M and C2M were significantly taller and heavier, had greater FFM, VO_2max, anaerobic power and capacity, and knee extension, shoulder internal/external rotation, and torso rotation strength than C1F and C2F. C1F demonstrated significantly greater BF% and FLI than C1M, C2F, and C2M. C1M and C2M demonstrated significantly greater relative VO_2max compared to C1F. C2M demonstrated significantly greater knee flexion strength than C1F and C2F, and C1M demonstrated significantly greater knee flexion strength than C1F. C2M demonstrated significantly greater ankle eversion and inversion strength than C1F. No significant differences were demonstrated among cluster and sex for age and LT.

4. Discussion

The purpose of this study was to investigate physical, physiological, and musculoskeletal characteristics of male and female Marines clustered by CFT performance: specifically, the MANUF and MTC. Women with greater BF% and Fight load index were associated with low CFT performance, and men with greater knee flexion and ankle strength were associated with high CFT performance. No other physical, physiological, or musculoskeletal strength measure was able to discriminate among the performance clusters within sex.

Cluster analysis was performed to determine which Marines had similar CFT performance, regardless of sex and physical/body composition characteristics. Overall, men in both clusters were taller and heavier, and had greater FFM than women in both clusters. Women in the cluster associated with lower CFT performance had significantly higher BF% than men in that cluster and women and men in the cluster associated with better CFT performance. Additionally, the Fight load index was significantly higher in this group of worse CFT performing women compared to the better CFT performing women, despite the fact that FFM and FM, which are components of the Fight load index, were not statistically different. This finding may indicate that FFM and FM relative to the fighting load may be a more important characteristic to consider for combat success in addition to BF%. These findings agree with

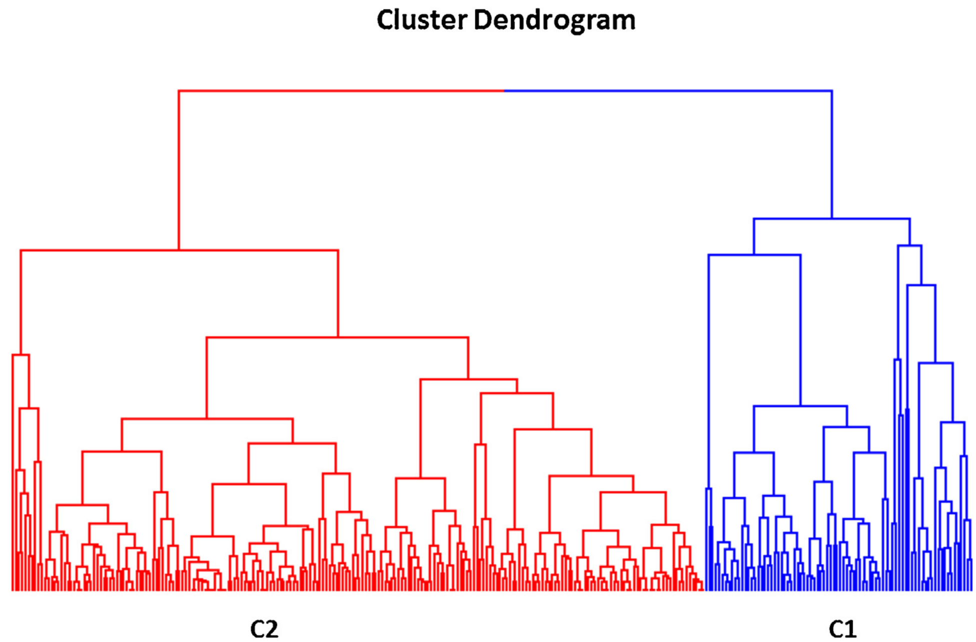

Fig. 1. To classify Marines based on performance of two CFT events (sec): Maneuver Under Fire (MANUF) (Mean: 157.8, SD: 27.0) and Movement to Contact (MTC) (Mean: 184.2, SD: 20.9), an agglomerative Hierarchical cluster analysis (HCA) was performed. The agglomerative HCA builds clusters from bottom to up. It starts with each subject as its own cluster and at each step, merges the closest clusters based on the distance metric and the linkage criteria until only one cluster remains. The cluster structure is displayed as a tree-like diagram, named dendrogram, selecting two clusters (C1 and C2).

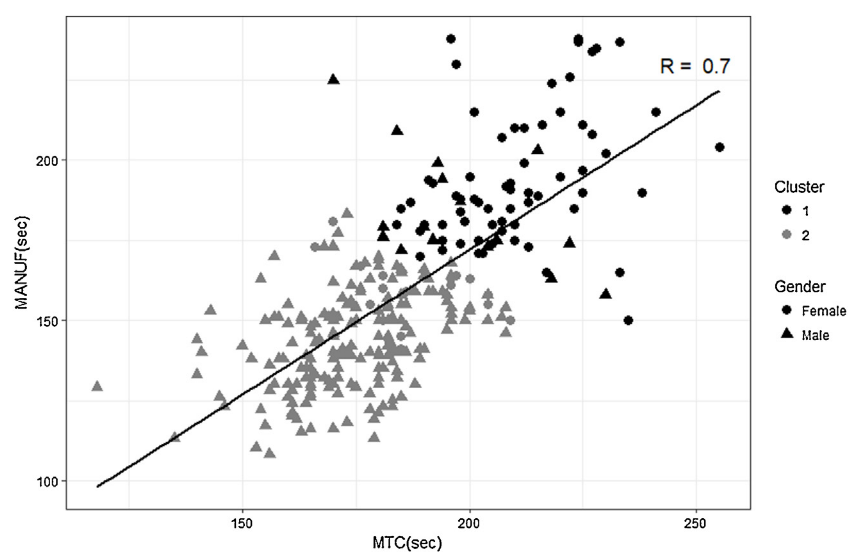

Fig. 2. The scatter plot of Marines (r = 0.7). X axis: Movement to Contact (MTC), Y axis: Maneuver Under Fire (MANUF). Black and Gray markers indicate Clusters 1 and 2, respectively, and dots represent female Marines and triangles represent male Marines.

previous research investigating association of fitness and body composition with military task performance, consisting of a test designed with typical army soldier maneuvers and tasks in combat dress uniform, such as change of direction, low crawl, sprint, obstacle, lifting/carrying, and agility tasks.[29] Pihlainen et al.[8] utilized a dead mass ratio (DMR) by dividing total body mass by the "dead mass", calculated as fat mass plus the weight of the combat load, and found that this parameter was the best predictor of military task performance. Together, these results further support the notion that excess body weight, carried as body fat, is detrimental to physical and physiological performance. A previous study demonstrated that in male Soldiers with similar amounts of FFM, those with increased levels of FM had significantly decreased aerobic and anaerobic capacity as well as decreased upper- and lower-body strength.[15] Thus, these results and results from the current study indicate female Marines may benefit from utilizing strategies to decrease FM and increase FFM to improve a range of combat-related performance characteristics.

Studies employing upper-body specific exercises have noted significant increases in lean mass of arms in young women,[30] and upper-body resistance training in women elicited mean increases of ~20% in MRI-assessed arm musculature.[31] Inherently, women possess less fat-free mass relative to men, as evidenced by the current study and previous research in military populations.[4] Since resistance training programs have been successful in increasing percent of whole body soft tissue lean mass in men and women,[32] this information can be utilized to enhance screening capabilities and inform training programs optimizing total force readiness,

Table 1
Demographic, body composition, physiological, and strength characteristics of Cluster 1 and Cluster 2 by sex.

	Cluster 1 — worse CFT performance				Cluster 2 — better CFT performance				
	Female Marines		Male Marines		Female Marines		Male Marines		
	N = 66		N = 16		N = 18		N = 194		
Demographics	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-Value
Age	22.67	2.83	22.75	2.08	22.44	2.57	22.34	2.43	0.740[e]
Height (m)	1.63[b,d]	0.05	1.75[a,c]	0.08	1.65[b,d]	0.06	1.74[a,c]	0.08	<0.001[e]
Weight (kg)	64.33[b,d]	6.77	79.54[a,c]	11.63	64.29[b,d]	8.37	80.80[a,c]	10.54	<0.001
Body comp	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-Value
BF%	25.25[b,c,d]	4.72	20.51[a]	6.13	21.22[a]	4.18	18.75[a]	5.98	<0.001
FFM (kg)	48.00[b,d]	5.20	62.82[a,c]	7.60	50.50[b,d]	5.88	65.35[a,c]	7.52	<0.001
FM (kg)	16.33	3.86	16.72	6.42	13.79	3.81	15.45	6.07	0.150[e]
Fight load index (FLI)	1.12[b,c,d]	0.14	0.86[a,c]	0.11	1.01[a,b,d]	0.10	0.81[a,c]	0.12	<0.001[e]
Physiology	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-Value
Mean anaerobic power (W)	362.69[b,d]	76.64	524.24[a,c]	90.04	378.12[b,d]	78.09	596.68[a,c]	115.23	<0.001
Peak anaerobic power (W)	676.19[b,d]	91.99	977.61[a,c]	185.73	689.57[b,d]	121.91	1004.34[a,c]	173.25	<0.001[e]
VO_2max (ml/min)	2814.78[b,d]	322.87	3812.56[a,c]	688.60	2967.99[b,d]	408.64	3947.57[a,c]	504.34	<0.001[e]
VO_2max (ml/kg/min)	43.86[b,d]	3.71	47.91[a]	4.39	46.02	4.62	49.11[a]	4.59	<0.001[e]
LT (%VO2 Max)	84.60	5.41	82.60	5.28	84.92	6.00	83.43	6.00	0.362
Strength	Mean	SD	Mean	SD	Mean	SD	Mean	SD	p-Value
Knee extension strength (Nm)	124.58[b,d]	21.38	180.81[a,c]	38.69	130.51[b,d]	29.68	185.15[a,c]	42.20	<0.001
Knee flexion strength (Nm)	66.50[b,d]	12.51	91.64[a]	26.32	73.24[d]	16.45	99.46[a,c]	22.09	<0.001
Shoulder external rotation strength (Nm)	19.90[b,d]	3.30	32.76[a,c]	5.61	20.58[b,d]	3.97	34.20[a,c]	6.98	<0.001[e]
Shoulder internal rotation strength (Nm)	25.06[b,d]	5.28	44.51[a,c]	12.51	25.54[b,d]	7.67	47.14[a,c]	13.12	<0.001[e]
Torso rotation strength (Nm)	73.86[b,d]	17.18	112.29[a,c]	29.16	82.07[b,d]	22.02	117.61[a,c]	29.26	<0.001[e]
Ankle eversion strength (kg)	26.16[d]	5.68	29.56	9.52	27.56	5.36	30.15[a]	6.24	<0.001[e]
Ankle inversion strength (kg)	22.85[d]	5.12	25.37	7.49	23.62	5.57	26.32[a]	6.31	0.001[e]

[a] Significantly different than Group 1 female Marines.
[b] Significantly different than Group 1 male Marines.
[c] Significantly different than Group 2 female Marines.
[d] Significantly different than Group 2 male Marines.
[e] Non-parametric tests conducted; Fight load index (FLI) = (fight load + FM)/FFM.

including the potential for pre-enlistment programs that establish a baseline level of upper-body strength/lean mass. Nindl et al. demonstrated a 2.2% increase in soft tissue lean mass after six months of periodized physical training.[32] This intervention, which included concurrent resistance and aerobic training, also was successful in reducing fat mass. Notably, vast difference emerged in tissue changes in arms and legs, with arms exhibiting a ~31% fat mass decrease and no soft tissue lean mass change, and legs exhibiting a 5.5% increase in soft tissue lean mass but no change in fat mass.[32] Thus, targeted upper-body resistance training programs, in conjunction with training to optimize total body strength, power, and aerobic fitness, may aid in increasing region-specific fat-free mass and enhancing muscular strength. These programs must be implemented carefully and in a periodized fashion, as concurrent aerobic and resistance programs may mitigate lean tissue and strength gains.[33]

Findings of the current study provide practical insight in identifying male and female Marines with enhanced characteristics deemed critical for safe and successful participation across combat MOS, and in providing information as to which characteristics may be targeted in specialized training programs. Overall, male Marines in both clusters demonstrated increased upper-body, lower-body, and trunk/torso strength; lower body anaerobic power and capacity; and increased aerobic capacity. The physiological demand of the MTC and MANUF is highly anaerobic, but aerobic capacity may help mitigate fatigue as these events last several minutes and incorporate repeated bouts of high intensity activity. Previous research has demonstrated women may enhance upper-body strength and movement under load with targeted training programs,[34,35] and periodized training programs are effective in reducing injury rates in military personnel;[36] thus, implementing such programs may assist in narrowing the physiological and strength performance gaps noted in this study and others.[4] A 24-week physical training program implemented in women, including aerobic and resistance training, as well as lifting/carrying and specialized drills, was successful in increasing occupational lifting strength and endurance, increasing jump performance, and decreased a load carriage for time task, indicating that women can significantly improve performance on physically-demanding military occupational tasks and decrease performance gaps among men and women.[6]

Interestingly, relative VO_2max, knee flexion strength and ankle inversion/eversion strength were the only characteristics that did not follow the trend of male Marines in both clusters demonstrating significantly better strength compared to female Marines in both clusters. Previous research has demonstrated that knee flexion strength fatigability is related to knee proprioception, which is an important characteristic for injury prevention and performance optimization.[37] Additionally, a recent study has demonstrated that ankle strength is an important characteristic in predicting graduation of ground combat MOS school in female Marines.[38] However, the distribution of male and female Marines among clusters and range of results within sex and cluster may have impacted the results of the current study, so they should be interpreted with caution. While lower-body anaerobic power and capacity were significantly greater in male Marines in both clusters, no differences were demonstrated in lactate threshold among cluster and sex. This finding may have been a limitation of collecting lactate data simultaneously during the VO_2max collection, impacting calculation of a true anaerobic threshold. An additional limitation of this study is that the CFT was conducted previous to the collection of laboratory characteristics, so the system-level characteristics collected in the laboratory may have differed from the time in which the most recent CFT was conducted. Performance of the CFT may have also been biased by inter-individual variability in conduct of the casualty evacuation and grenade throw accuracy. Additionally, while maximal effort performance was encouraged during laboratory testing, the authors cannot guarantee the events of the CFT were performed at maximal effort versus achieving minimal scores needed to pass.[15]

5. Conclusions

Female Marines in the better performing CFT cluster demonstrated less BF% and FLI compared to female Marines in the worse performing cluster, while male Marines in the better performing and worse performing CFT cluster demonstrated similar body composition, physiological, and strength characteristics. Body composition, particularly BF% and the ratio of fat mass plus fight load relative to fat free mass relative to the fighting load, may be an important consideration for combat success. In order to optimize body composition as well as reduce the sex gap in physiological and strength capabilities, male and female Marines may benefit from periodized resistance training programs. These programs should be targeted to enhance overall fitness for readiness depending on the individual Marine's physical profile and baseline body composition and fitness characteristics.

Acknowledgments

This work was supported by Office of Naval Research (ONR) #N00014-14-1-0021. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ONR or United States Marine Corps. The authors would like to thank Megan Frame, Yosuke Kido, Corey O'Connor, and Kathleen Poploski, as well as Lt. Col Misty Posey, USMC and Col Anne M. Weinberg, USMC (retired) for their contributions to this research.

References

1. Nindl BC, Jones BH, Van Arsdale SJ et al. Operational physical performance and fitness in military women: physiological, musculoskeletal injury, and optimized physical training considerations for successfully integrating women into combat-centric military occupations. *Mil Med* 2016; 181(1S):50–62.
2. Sauers SE, Scofield DE. Strength and conditioning strategies for females in the military. *Strength Cond J* 2014; 36(3):1–7.
3. Friedl KE, Knapik JJ, Hakkinen K et al. Perspectives on aerobic and strength influences on military physical readiness: report of an international military physiology roundtable. *J Strength Cond Res* 2015; 29(Suppl 11):S10–S23.
4. Allison KF, Keenan KA, Sell TC et al. Musculoskeletal, biomechanical, and physiological gender differences in the US military. *Army Med Dep J* 2015:12–22.
5. Dada EO, Anderson MK, Grier T et al. Sex and age differences in physical performance: a comparison of army basic training and operational populations. *J Sci Med Sport* 2017; 20(Suppl 4):S68–S73.
6. Nindl BC, Eagle SR, Frykman PN et al. Functional physical training improves women's military occupational performance. *J Sci Med Sport* 2017; 20(Suppl 4):S91–S97.
7. United States Marine Corps. *United States Marine Corps Ground Combat Element Integrated Task Force Research: Final Report*, University of Pittsburgh, 2015. p. 116.
8. Pihlainen K, Santtila M, Hakkinen K et al. Associations of physical fitness and body composition characteristics with simulated military task performance. *J Strength Cond Res* 2018; 32(4):1089–1098.
9. Buskirk E, Taylor HL. Maximal oxygen intake and its relation to body composition, with special reference to chronic physical activity and obesity. *J Appl Physiol* 1957; 11(1):72–78.
10. Cathcart E, Richardson D, Campbell W. Army hygiene advisory committee report no: 3. On the maximum load to be carried by the soldier. *J R Army Med Corps* 1923; 41(3):161–178.
11. Lyons J, Allsopp A, Bilzon J. Influences of body composition upon the relative metabolic and cardiovascular demands of load-carriage. *Occup Med (Lond)* 2005; 55(5):380–384.
12. Sulsky SI, Bulzacchelli MT, Zhu L et al. Risk factors for training-related injuries during U.S. army basic combat training. *Mil Med* 2018; 183(suppl_1):55–65.
13. Bartlett JL, Phillips J, Galarneau MR. A descriptive study of the US Marine corps fitness tests (2000–2012). *Mil Med* 2015; 180(5):513–517.
14. Schöllhorn W, Chow JY, Glazier P et al. *Self-organising maps and cluster analysis in elite and sub-elite athletic performance*, London, Routledge, 2014.
15. Crawford K, Fleishman K, Abt JP et al. Less body fat improves physical and physiological performance in army soldiers. *Mil Med* 2011; 176(1):35–43.
16. Noreen EE, Lemon PWR. Reliability of air displacement plethysmography in a large, heterogeneous sample. *Med Sci Sports Exerc* 2006; 38(8):1505–1509.
17. Hoffman J, Epstein S, Einbinder M et al. A comparison between the Wingate anaerobic power test to both vertical jump and line drill tests in basketball players. *J Strength Cond Res* 2000; 14(3):261–264.
18. Kang J, Chaloupka EC, Mastrangelo MA et al. Physiological comparisons among three maximal treadmill exercise protocols in trained and untrained individuals. *Eur J Appl Physiol* 2001; 84(4):291–295.
19. Abt JP, Oliver JM, Nagai T et al. Block-periodized training improves physiological and tactically relevant performance in naval special warfare operators. *J Strength Cond Res* 2016; 30(1):39–52.
20. Crouter SE, Antczak A, Hudak JR et al. Accuracy and reliability of the ParvoMedics TrueOne 2400 and MedGraphics VO2000 metabolic systems. *Eur J Appl Physiol* 2006; 98(2):139–151.
21. Attinger A, Tuller C, Souren T et al. Feasibility of mobile cardiopulmonary exercise testing. *Swiss Med Wkly* 2006; 136(1–2):13–18.
22. Abt JP, Oliver JM, Nagai T et al. Block-periodized training improves physiological and tactically relevant performance in naval special warfare operators. *J Strength Cond Res* 2016; 30(1):39–52.
23. Drouin JM, Valovich-mcLeod TC, Shultz SJ et al. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *Eur J Appl Physiol* 2004; 91(1):22–29.
24. Kelln BM, McKeon PO, Gontkof LM et al. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active,young adults. *J Sport Rehabil* 2008; 17(2):160–170.
25. Spink MJ, Fotoohabadi MR, Menz HB. Foot and ankle strength assessment using hand-held dynamometry: reliability and age-related differences. *Gerontology* 2010; 56(6):525–532.
26. Tan P-N, Steinbach M, Kumar V. *Introduction to data mining*, 1st ed. Boston, Pearson Addison Wesley, 2005, xxi.
27. Ball KA, Best RJ. Different centre of pressure patterns within the golf stroke I: cluster analysis. *J Sports Sci* 2007; 25(7):757–770.
28. R. Core Team. *R: A language and environment for statistical computing*, Vienna, Austria, R Foundation for Statistical Computing, 2013.
29. Pihlainen K, Santtila M, Hakkinen K et al. Associations of physical fitness and body composition characteristics with simulated military task performance. *J Strength Cond Res* 2018; 32(4):1089–1098.
30. Chilibeck PD, Calder AW, Sale DG et al. A comparison of strength and muscle mass increases during resistance training in young women. *Eur J Appl Physiol Occup Physiol* 1998; 77(1–2):170–175.
31. Kraemer WJ, Nindl BC, Ratamess NA et al. Changes in muscle hypertrophy in women with periodized resistance training. *Med Sci Sports Exerc* 2004; 36(4):697–708.
32. Nindl BC, Harman EA, Marx JO et al. Regional body composition changes in women after 6 months of periodized physical training. *J Appl Physiol* 2000; 88(6):2251–2259.
33. Vaara JP, Kokko J, Isoranta M et al. Effects of added resistance training on physical fitness, body composition, and serum hormone concentrations during eight weeks of special military training period. *J Strength Cond Res* 2015; 29(Suppl 11):S168–S172.
34. Kraemer WJ, Mazzetti SA, Nindl BC et al. Effect of resistance training on women's strength/power and occupational performances. *Med Sci Sports Exerc* 2001; 33(6):1011–1025.
35. Kraemer WJ, Vescovi JD, Volek JS et al. Effects of concurrent resistance and aerobic training on load-bearing performance and the Army physical fitness test. *Mil Med* 2004; 169(12):994–999.
36. Groeller H, Burley SD, Sampson JA et al. A periodised, low volume high training load regimen reduces the rate of recruit injury within basic military training: 949 board #265 June 1, 2: 00 PM–3: 30 PM. *Med Sci Sports Exerc* 2016; 48(5 Suppl 1):270.
37. Allison KF, Abt JP, Beals K et al. Aerobic capacity and isometric knee flexion strength fatigability are related to knee kinesthesia in physically active women. *Isokinet Exerc Sci* 2016; 24(4):357–365.
38. Allison KF, Keenan KA, Wohleber MF et al. Greater ankle strength, anaerobic and aerobic capacity, and agility predict Ground Combat Military Occupational School graduation in female Marines. *J Sci Med Sport* 2017; 20(Suppl 4):S85–S90.