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The Effect of Occupational Integration on Musculoskeletal Injury in Female Marines in the Fleet: An Epidemiological Cohort Study

Short title: Musculoskeletal Injury in Female Marines

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ABSTRACT

Introduction:

Musculoskeletal injuries (MSKIs) are ubiquitous in the U.S. military, especially among high-performing service members such as Marines. Given that female service members only started to be assigned to ground combat roles since December 2015, evaluation of sex on MSKI risk in ground combat occupations has not been possible until there was an ample population to study. The purpose of this population-level epidemiological study was to assess (1) if female sex was a salient risk factor for MSKI in Marines serving in different military occupations, including combat arms, and (2) the effects of integration period on MSKI risk among female Marines.

Materials and Methods:

A population-based epidemiological retrospective cohort study of all U.S. Marines was performed assessing female sex, occupation, and integration period on the prevalence of MSKI from 2011 through 2020. The Military Health System Data Repository was utilized to identify initial healthcare encounters for diagnosed ankle-foot, knee, lumbopelvic-hip, thoracocostal, cervicothoracic, shoulder, elbow, or wrist-hand complex injuries. Prevalence was calculated for female and male Marines in each occupational category (combat, combat support, aviators, aviation support, services) during the pre-integration (2011–2015) and post-integration (2016–2020) periods.

Results:

During the pre-integration period, 520/1,000 female Marines (*n*=13,985) and 299/1,000 male Marines (*n*=142,158) incurred MSKIs. In the post-integration period, the prevalence increased to 565/1,000 female Marines (*n*=17,608) and 348/1,000 male Marines (*n*=161,429). In the multivariable evaluation of sex, occupation, integration period, and the interaction of sex and

occupation on combined MSKIs, only female sex was a significant factor for injury (prevalence ratio [PR]=1.99), with service in ground combat and aviation occupations identified as protective factors when compared with services occupations (PR=0.69). When these same factors were evaluated for specific MSKI outcomes, female sex remained a robust factor in all lower quarter (PR=1.75–2.63) and upper quarter (PR=1.38–2.36) injuries except for shoulder injuries. Service in ground combat and aviation occupations was protective for all lower quarter injuries (PR=0.46–0.71). In the upper quarter, ground combat was protective for all injuries except for elbow injuries (PR=0.67–0.77). Serving as an aviator was a risk factor for cervicothoracic (PR=1.57) and thoracocostal (PR=1.22) injuries and a protective factor for shoulder (PR = 0.73) and wrist-hand (PR = 0.46) injuries. Adjusted risk for lumbopelvic-hip (PR=1.13), ankle-foot (PR=1.53), cervicothoracic (PR=1.19), thoracocostal (PR=1.14), and elbow (PR=1.48) injuries significantly increased during the post-integration period. There was a significant sex-by-period interaction for shoulder injuries alone, with female sex in the post-integration epoch found to be salient (PR=1.26).

Conclusions:

Female sex was a salient factor for MSKI, with service in ground combat and aviation occupations identified as protective factors when compared with services occupations. In the evaluation of specific MSKIs, female sex remained a robust and significant factor in all lower quarter injuries and upper quarter injuries except for shoulder injuries. There was only a significant sex-by-period interaction for shoulder conditions, with an increased risk of these injuries in female Marines in the post-integration period.

INTRODUCTION

Musculoskeletal injuries (MSKIs) are highly prevalent in the U.S. military, especially among high-performing service members such as Marines. MSKI episodes occurred at a rate of 1,004.73 episodes per 1,000 person-years in U.S. Marines between December 2016 and August 2021.[1] In garrison, these conditions pose a substantial threat to operational readiness, affecting service members' ability to train and deploy to meet unit and national objectives.[1] MSKIs, which include both macrotraumatic (categorized as injury/poisoning) and repetitive microtraumatic (categorized as musculoskeletal disease) diagnostic categories, are the leading medical conditions in the Military Health System (MHS) and affect more service members than any other category.[2] This does not change when service members deploy.[3] When macrotraumatic and repetitive microtraumatic diagnostic categories are combined, MSKIs are the leading medical conditions that result in medical evacuation of deployed service members out of the operational theater.[4] The most recent finding of MSKI as a leading nonbattle injury and reason for medical evacuation is consistent with the findings reported by Cohen and colleagues in 2010,[5] who also found that U.S. Marines had the lowest return-to-duty rates following evacuation among the service branches deployed to the Iraq and Afghanistan conflicts.

Female service members have greater injury risk than their male counterparts in the same occupation for various musculoskeletal conditions in the lower extremity.[1,6–11] This is likely a result of not only biomechanical and physiological factors, but also psychosocial determinants of care-seeking following the onset of symptoms or injury-related impairment.[1,6–14] The evidence suggests that military occupations not only have varying physical loads and environmental exposures that may affect injury risk, but also unique cultures that may influence care-seeking.[7,9–14] This is especially true within combat arms occupations in the Fleet Marine Force.

To project power in austere, uncertain, and arduous conditions under the threat of harm at "the tip of the spear," ground combat occupations are composed of service members that are proactive, mission centered, highly resilient, and have substantial grit. Not dissimilar to care-seeking behaviors in athletes, service cultures within combat arms likely promote self-management and reduce care-seeking following injury.[12] The cultural factors in ground combat occupations that preclude care-seeking may plausibly counteract the positive care-seeking behaviors typically observed in women. Given that female service members have only been assigned to ground combat roles since December 2015,[15] evaluation of sex and MSKI risk in ground combat occupations has not been possible until there was an ample population to study. Therefore, the purpose of this population-level epidemiological study was to assess (1) if female sex was a salient risk factor for MSKI in Marines serving in different military occupations, including combat arms, and (2) the effects of the integration period on MSKI risk among female Marines. We hypothesized that female service members would demonstrate greater musculoskeletal injury risk compared with male service members, particularly in combat occupations. Due to the changes in occupational and training exposure following the policy change, which likely had service-wide effects, we anticipated that there would be higher risk of MSKI in female Marines in the post-integration period compared with the pre-integration period.

METHODS

A population-based epidemiological retrospective cohort study of all service members in the U.S. Marine Corps from 2011 through 2020 was performed assessing female sex, occupation, and integration period on the prevalence of MSKIs. The Military Health System Data Repository (MDR) was utilized to identify relevant healthcare encounters. This study was approved by the

Naval Health Research Center Institutional Review Board. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines were used to guide reporting.[16]

Diagnosis codes for MSKI were derived and categorized by regional complex using the Neuromusculoskeletal Epidemiological Outcome (NEO) Matrix.[17] The database was queried for the number of distinct Marines seen in the MHS on their initial encounter and diagnosed with an ankle-foot, knee, lumbopelvic-hip, thoracocostal, cervicothoracic, shoulder, elbow, or wrist-hand complex injuries.[17] Prevalence was calculated for female and male Marines in each occupational category (combat, combat support, aviators, aviation support, services) during the pre-integration (2011–2015) and post integration (2016–2020) periods.

Prevalence ratio (PR) point estimates and 95% confidence intervals (CIs), risk difference, attributable risk, and chi-squared statistics were calculated in the assessments of sex and integration period (in female Marines) using Microsoft Excel for Mac 2016 (Microsoft Corp., Redmond, WA) and a custom epidemiological spreadsheet.[18] In the unadjusted assessment of MSKI risk stratified by body region, male Marines and the 5-year pre-integration period served as reference groups.

Adjusted multivariable models were employed to assess the effects of sex, occupation, integration period, and sex-by-period interaction on counts of musculoskeletal injury for each body region, normalized to the at-risk population. Due to overdispersion of the data, a negative binomial model was employed over a Poisson model.[19] The regression analyses were performed using the 'MASS' package (version 7.3-60.0.1) on R (version 4.3.3, The R Foundation for Statistical Computing, Vienna, Austria). The level of significance was $p < .05$ for all analyses. PR point estimates were considered statistically significant if CIs did not cross the 1.00 threshold.

Convergence of *p*-values, effect sizes, and 95% CIs were considered when evaluating significant findings.

RESULTS

During the pre-integration period (2011–2015), 520 per 1,000 female Marines (*n* = 13 985) and 299 per 1,000 male Marines (*n* = 142,158) incurred MSKIs. In the post-integration period (2016–2020), the prevalence increased to 565 per 1,000 female Marines (*n* = 17,608) and 348 per 1,000 male Marines (*n* = 161,429). The pre-integration and post-integration prevalence in male and female Marines in each occupational category are detailed in Table 1. Supplemental Figure 1 illustrates the changes in MSKI prevalence over time in male and female Marines serving in each occupational category and for all occupations combined.

In the unadjusted assessment of sex on MSKI (stratified by body region) during the post-integration period, female sex was a significant factor for all lower quarter injuries (PR = 1.62–2.93) and thoracocostal, cervicothoracic, and wrist-hand injuries in the upper quarter (PR = 1.26–2.25) (Table 2). In the evaluation of the effects of integration in female Marines, there was a significantly higher prevalence of ankle-foot (PR = 1.29) and lumbopelvic-hip injuries (PR = 1.23) in the lower quarter and all upper quarter injuries (PR = 1.17–1.46) following integration (Table 3).

Supplemental Figure 2 illustrates the direct acyclic graph detailing the effects of sex and occupation with moderation of integration period on musculoskeletal injury. In the multivariable evaluation of sex, occupation, integration period, and the interaction of sex and occupation on combined MSKI, only female sex was a salient factor for injury (PR = 1.99), with service in ground combat and aviation occupations identified as protective factors compared with services

occupations (PR = 0.69) (Table 4). When these same factors were evaluated in the risk for specific MSKIs, female sex remained a robust and salient factor in all lower quarter injuries (PR = 1.75–2.63) and upper quarter injuries (PR = 1.38–2.36) except for shoulder injuries (Supplemental Tables 1 and 2). Service in ground combat and aviation occupations were protective for all lower quarter injuries (PR = 0.46–0.71). In the upper quarter, ground combat was protective for all but elbow injuries (PR = 0.67–0.77). Serving as an aviator was a risk factor for cervicothoracic (PR = 1.57) and thoracocostal (PR = 1.22) injuries and a protective factor for shoulder (PR = 0.73) and wrist-hand (PR = 0.46) injuries. Less than half of the upper and lower quarter MSKI categories were significantly different when comparing ground combat support and aviation support with services occupations. Adjusted risk for lumbopelvic-hip (PR = 1.13), ankle-foot (PR = 1.53), cervicothoracic (PR = 1.19), thoracocostal (PR = 1.14), and elbow (PR = 1.48) injuries significantly increased during the post-integration period. There was a significant sex-by-period interaction for shoulder injuries alone, with female sex in the post-integration epoch found to be salient (PR = 1.26).

DISCUSSION

The primary findings of this study were that female sex was a salient factor in both the pre-integration and post-integration periods for overall MSKI risk. During the post-integration period, female sex was a salient factor for all lower quarter injuries and thoracocostal, cervicothoracic, and wrist-hand injuries compared with male Marines. There was a higher prevalence of ankle-foot and lumbopelvic-hip injuries in the lower quarter and all upper quarter injuries in women following integration. Once adjusted for occupation, integration period, and the interaction of sex and occupation on overall MSKI risk, female sex was a salient factor for

injury, with service in ground combat and aviation occupations identified as protective factors compared with services occupations. In the evaluation of specific MSKIs, female sex remained a robust and salient factor in all lower quarter injuries and upper quarter injuries except for shoulder injuries. There was only a significant sex-by-period interaction for shoulder conditions, with an increased risk of these injuries in female Marines in the post-integration period. This is the first study, to our knowledge, to have evaluated MSKI risk in female service members serving in the Fleet Marine Force following integration.

Our finding that female Marines have a significant higher overall risk of MSKI compared with their male counterparts is consistent with previous studies.[1,20] The prevalence of MSKI conditions significantly increased during the post-integration period in all body regions except for knee injuries. In the post-integration period, there was a noted reduction in injuries during 2020, a finding consistent with another study reporting the effects of the pandemic on MSKI risk.[1] When adjusted MSKI risk was assessed with consideration of military occupation, female sex continued to be a robust and significant factor. Despite increased prevalence of MSKI in both female and male Marines during the post-integration period, the interaction of sex and period was not significant.

Among the occupations, the combat and aviator occupational communities had a significantly lower risk of MSKI once sex was factored in. This was consistent among all lower extremity, thoracocostal, lumbopelvic-hip, and shoulder injuries. The risk of MSKI in the combat support and aviation support occupations was not significantly different from that observed in services. It is plausible that there are cultural or geographic factors for increased diagnosis of these conditions in the support and services occupations. It is plausible that support and service fields are closer to medical support (fewer geographic barriers to care) and have occupational

cultures that are more accepting and facilitate medical care-seeking.[12,13] Ground and aviation combat occupations attract Marines that are resilient and more likely to self-manage symptoms. By avoiding care-seeking, perceived threat of being removed from operational duties (e.g., patrol or grounding from flight) and the appearance of weakness can be avoided.[12,13] These suppositions, including care-seeking behaviors for MSKIs among female and male Marines serving in the different occupational communities, warrant further investigation.

Clinical and Policy Implications

The findings in the current study can be used to plan mitigation strategies needed to ameliorate risk factors and the specialized medical capabilities needed to address these conditions in the Marines Corps. This is especially salient as more women have increasing involvement in ground combat operations. These findings further illustrate the need for surveillance and prevention programs “left of boom,” and integrated musculoskeletal specialists, including sports medicine physicians, physical therapists, and athletic trainers for in-garrison care. Once deployed, increased numbers of uniformed Navy sports medicine physicians and physical therapists are needed to provide prompt primary care to Marines in the austere operational environment while shipboard and when projected ashore. This recommendation is a stark departure from the current medical capability provided for Marines. While there are some specialized capabilities provided by Navy Medicine (Sports Medicine and Reconditioning Team; Navy Physical Therapy MSKI) and the Marine Corps (Marine Corps Sports Medicine Injury Prevention) for Marines in garrison, expansion of the interdisciplinary sports medicine programs is needed. Furthermore, there are no established Marine Corps requirements or doctrine that provide for non-trauma MSKI care in Role I–III settings. Establishment of specific requirements, integration into the medical annex of

operational plans, and proper resourcing (i.e., Navy Sports Medicine Physicians and Physical Therapists in the table of organization) will ensure both female and male Marines are ready to fight while in garrison, afloat, and when projected ashore in the operational environment.

Limitations

There are limitations to this study. First, estimates of MSKIs relied on healthcare encounters in the Medical Data Repository. Since undocumented care, documented care that was privately procured external to the healthcare benefit, or self-care would not be reflected in our results, the true prevalence of MSKI in the Marine Corps is likely much greater than that reported in this study. This is especially true in the ground and aviation combat occupations, where it is estimated that approximately 37% of Marines do not seek care for these injuries.[12] The epoch employed during the study occurred during a period of relative peacetime. It is unclear if these findings would be influenced by large-scale conflict, which would limit generalizability.

CONCLUSION

Female sex was a salient factor for MSKI, with service in ground combat and aviation occupations identified as protective factors when compared with services occupations. In the evaluation of specific MSKIs, female sex remained a robust and salient factor in all lower quarter injuries and upper quarter injuries except for shoulder injuries. There was only a significant sex-by-period interaction for shoulder conditions, with an increased risk of these injuries in female Marines in the post-integration period.

REFERENCES

1. Fraser JJ, MacGregor AJ, Fechner KM, Galarneau MR. Factors Associated With Neuromusculoskeletal Injury and Disability in Navy and Marine Corps Personnel. *Mil Med*. Published online December 14, 2022:usac386. doi:10.1093/milmed/usac386
2. Armed Forces Health Surveillance Division. Absolute and relative morbidity burdens attributable to various illnesses and injuries, active component, US Armed Forces, 2023. *MSMR*. 2024;31(6):2-10.
3. Armed Forces Health Surveillance Division. Morbidity burdens attributable to various illnesses and injuries among deployed active and reserve component service members of the US armed forces, 2023. *MSMR*. 2024;31(7):7-10.
4. Armed Forces Health Surveillance Division. Medical evacuations out of the US Central and US Africa Commands, active and reserve components, US Armed Forces, 2023. *MSMR*. 2024;31(7):2-6.
5. Cohen SP, Brown C, Kurihara C, Plunkett A, Nguyen C, Strassels SA. Diagnoses and factors associated with medical evacuation and return to duty for service members participating in Operation Iraqi Freedom or Operation Enduring Freedom: a prospective cohort study. *The Lancet*. 2010;375(9711):301-309. doi:10.1016/S0140-6736(09)61797-9
6. Aguero AD, Irrgang JJ, MacGregor AJ, Rothenberger SD, Hart JM, Fraser JJ. Sex, military occupation and rank are associated with risk of anterior cruciate ligament injury in tactical-athletes. *BMJ Mil Health*. Published online February 13, 2022:e002059. doi:10.1136/bmjmilitary-2021-002059

7. Fraser JJ, MacGregor AJ, Ryans CP, Dreyer MA, Gibboney MD, Rhon DI. Sex and occupation are salient factors associated with lateral ankle sprain risk in military tactical athletes. *J Sci Med Sport*. 2021;24(7):677-682. doi:10.1016/j.jsams.2021.02.016
8. Fraser JJ, Ryans CP, MacGregor AJ, Janney CF. Macrotraumatic Fractures of the Multisegmented Ankle-Foot Complex in Military Tactical Athletes: A Cohort Study. *J Am Podiatr Med Assoc*. 2023;113(6):22-114. doi:10.7547/22-114
9. MacGregor AJ, Fogleman SA, Dougherty AL, Ryans CP, Janney CF, Fraser JJ. Sex Differences in the Incidence and Risk of Ankle–Foot Complex Stress Fractures Among U.S. Military Personnel. *J Womens Health*. 2022;31(4):586-592. doi:10.1089/jwh.2021.0292
10. Sullivan CK, Janney CF, Fraser JJ. Burden and risk factors for Achilles tendinopathy in the military population from 2006 to 2015. A retrospective cohort study. *J Athl Train*. Published online September 21, 2023. doi:10.4085/1062-6050-0182.23
11. Barbeau P MSc, Michaud A BSc, Hamel C MSc, et al. Musculoskeletal Injuries Among Females in the Military: A Scoping Review. *Mil Med*. 2021;186(9-10):e903-e931. doi:10.1093/milmed/usaa555
12. Fraser JJ, Schmied E, Rosenthal MD, Davenport TE. Physical therapy as a force multiplier: population health perspectives to address short-term readiness and long-term health of military service members. *Cardiopulm Phys Ther J*. 2020;31(1):22-28. doi:10.1097/CPT.0000000000000129
13. Britt TW, Sipos ML, Klinefelter Z, Adler AB. Determinants of mental and physical health treatment-seeking among military personnel. *Br J Psychiatry*. 2020;217(2):420-426. doi:10.1192/bjp.2019.155

14. Dartt CE, Gregory AB, de la Motte SJ, Ricker EA. Determinants of medical care-seeking behavior for musculoskeletal conditions during US: Marine Corps training: A thematic analysis. *J Athl Train*. Published online June 19, 2024. doi:10.4085/1062-6050-0707.23
15. Kavanagh J, Wenger JW. Integrating Women Into the Marine Corps Infantry: Costs, Representation, and Lessons from Earlier Integration Efforts. *Def Peace Econ*. 2020;31(1):4-23. doi:10.1080/10242694.2018.1465675
16. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for reporting observational studies. *Int J Surg*. 2014;12(12):1495-1499. doi:10.1016/j.ijsu.2014.07.013
17. Fraser JJ, Rohrbeck P, MacGregor AJ. The Neuromusculoskeletal Epidemiological Outcome (NEO) matrix: An innovative injury classification based on anatomical location and primary tissue type. *Injury*. 2022;53(11):3692-3696. doi:10.1016/j.injury.2022.09.031
18. LaMorte W. Epidemiology/Biostatistics Tools [Excel workbook]. http://bit.ly/Lamort3. 2006. Accessed August 3, 2019. http://bit.ly/Lamort3
19. Cameron AC, Trivedi PK. *Regression Analysis of Count Data*. Vol 53. Cambridge university press; 2013.
20. Schram B, Canetti E, Orr R, Pope R. Injury rates in female and male military personnel: a systematic review and meta-analysis. *BMC Womens Health*. 2022;22(1):310. doi:10.1186/s12905-022-01899-4

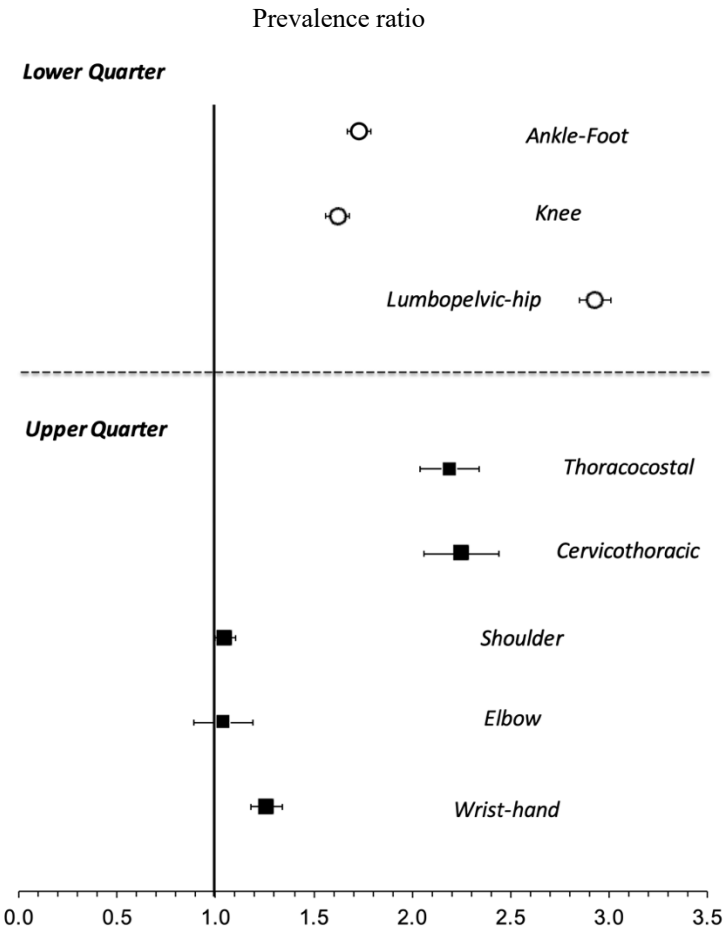
Table 1. Prevalence of Musculoskeletal Injuries (per 1,000 Marines) in U.S. Marines During the Pre-Integration (2011–2015) and Post-Integration Periods (2016–2020), Stratified by Military Occupational Category

Body region	Sex	Military occupational category									
		Combat		Combat support		Aviators		Aviation support		Services	
		Pre-integration	Post-integration	Pre-integration	Post-integration	Pre-integration	Post-integration	Pre-integration	Post-integration	Pre-integration	Post-integration
Ankle-Foot	Female	N/A	171.1	150.9	204.6	62.6	208.8	131.5	186.9	173.5	214.9
	Male	57.9	89.0	98.2	124.5	24.0	70.3	82.7	105.5	107.2	144.7
Knee	Female	NA	86.7	150.8	149.5	99.9	79.8	131.4	139.4	161.5	151.1
	Male	50.6	65.6	96.7	98.8	32.4	40.8	81.0	89.2	97.3	108.2
Lumbopelvic-Hip	Female	NA	261.3	231.1	289.6	107.5	149.3	224.4	280.3	241.1	292.5
	Male	48.7	69.4	85.0	109.5	63.2	64.7	163.9	98.7	85.8	111.7
Thoracocostal	Female	NA	34.1	51.6	60.0	43.5	41.6	55.0	56.9	48.9	61.6
	Male	14.5	19.3	24.4	30.8	33.8	26.8	24.1	25.6	21.9	30.9
Cervicothoracic	Female	NA	38.2	35.6	38.5	22.2	66.9	35.3	44.5	36.7	47.2
	Male	11.0	13.0	16.1	20.9	28.7	25.9	17.8	20.3	16.0	21.8
Shoulder	Female	NA	48.2	51.5	56.1	11.8	60.9	37.1	50.0	45.0	56.9
	Male	31.8	38.9	52.3	57.6	25.4	26.6	54.1	57.2	50.2	60.1
Elbow	Female	NA	33.6	8.7	13.7	15.4	6.7	8.5	15.7	10.9	14.4
	Male	6.9	10.6	8.6	15.0	5.6	7.5	11.0	15.0	10.1	14.9
Wrist-Hand	Female	NA	41.4	43.0	49.0	26.5	13.6	66.7	63.5	50.3	66.2
	Male	26.6	34.8	39.9	42.7	15.8	16.2	51.6	59.7	49.3	59.0

N/A: Not applicable because female Marines were excluded from combat occupations prior to integration.

Table 2. Assessment of Female Sex on Musculoskeletal Injuries, Stratified by Body Region, in U.S. Marines During the Post-Integration Period, 2016–2020

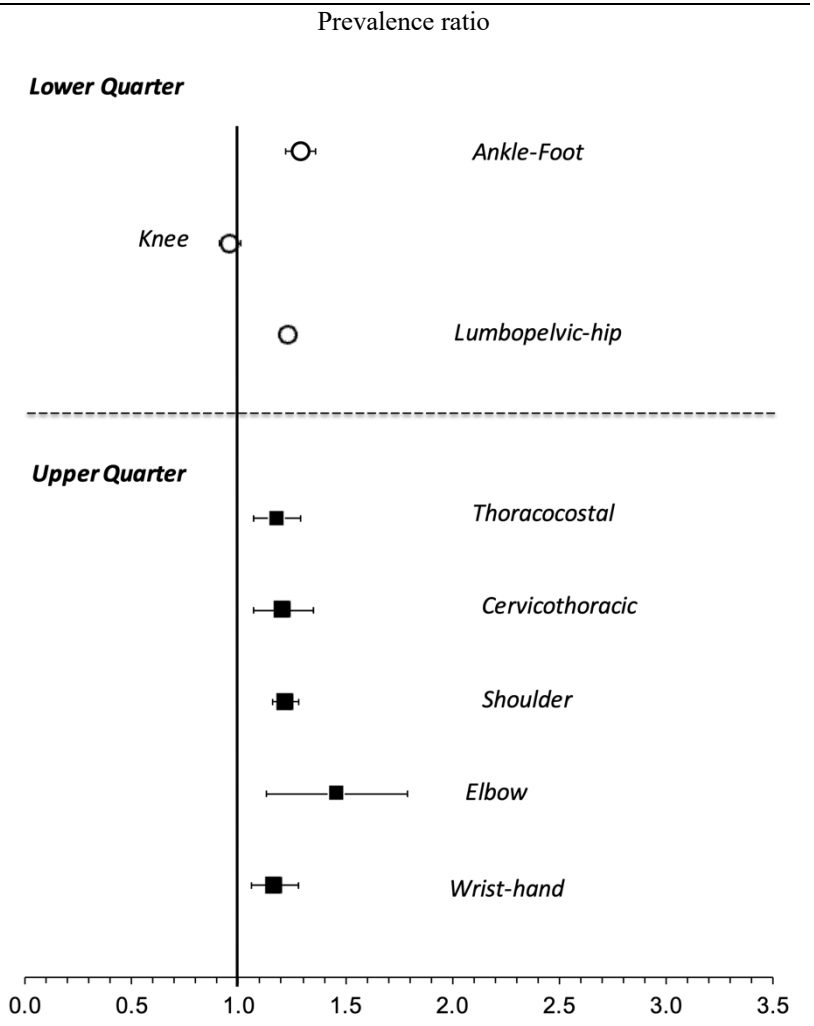
Body region	Sex	Prevalence (per 1,000 Marines)	Risk difference (per 1,000 Marines)	AR %	*p*
Lower quarter					
Ankle-Foot	Female	206.3	**87.3**	**42.3**	**<.001**
	Male	119.1	ref	ref	ref
Knee	Female	147.3	**56.4**	**38.3**	**<.001**
	Male	91.0	ref	ref	ref
Lumbopelvic-Hip	Female	288.1	**189.6**	**65.8**	**<.001**
	Male	98.5	ref	ref	ref
Upper quarter					
Thoracocostal	Female	59.8	**32.5**	**54.4**	**<.001**
	Male	27.3	ref	ref	ref
Cervicothoracic	Female	43.6	**24.2**	**55.6**	**<.001**
	Male	19.3	ref	ref	ref
Shoulder	Female	55.8	2.6	4.6	.15
	Male	53.2	ref	ref	ref
Elbow	Female	14.4	0.6	4.2	.52
	Male	13.8	ref	ref	ref
Wrist-Hand	Female	58.9	**12.1**	**20.6**	**<.001**
	Male	46.8	ref	ref	ref



AR, attributable risk; ref, female Marines referenced to male Marines. Bolded values indicate statistically significant findings.

Table 3. Assessment of Musculoskeletal Injury Risk in Female Marines, Stratified by Body Region, in the Post-Integration Period (2016–2020) Compared With the Pre-Integration Period (2011–2015)

Body region	Period	Prevalence (per 1,000 Marines)	Risk difference (per 1,000 Marines)	AR %	*p*
Lower quarter					
Ankle-Foot	Post-integration	206.3	**46.7**	**22.6**	**<.001**
	Pre-integration	159.7	ref	ref	ref
Knee	Post-integration	147.3	-5.7	-3.9	.16
	Pre-integration	153.0	ref	ref	ref
Lumbopelvic-Hip	Post-integration	288.1	**53.1**	**18.4**	**<.001**
	Pre-integration	235.0	ref	ref	ref
Upper quarter					
Thoracocostal	Post-integration	59.8	**9.0**	**15.0**	**<.001**
	Post-integration	50.8	ref	ref	ref
Cervicothoracic	Post-integration	43.6	**7.5**	**17.3**	**<.001**
	Pre-integration	36.0	ref	ref	ref
Shoulder	Post-integration	55.8	**10.1**	**18.2**	**<.001**
	Pre-integration	45.7	ref	ref	ref
Elbow	Post-integration	14.4	**4.5**	**31.3**	**<.001**
	Pre-integration	9.9	ref	ref	ref
Wrist-Hand	Post-integration	58.9	**8.6**	**14.5**	**<.001**
	Pre-integration	50.3	ref	ref	ref



AR, attributable risk; ref, post-integration period referenced to pre-integration. Bolded values indicate statistically significant findings.

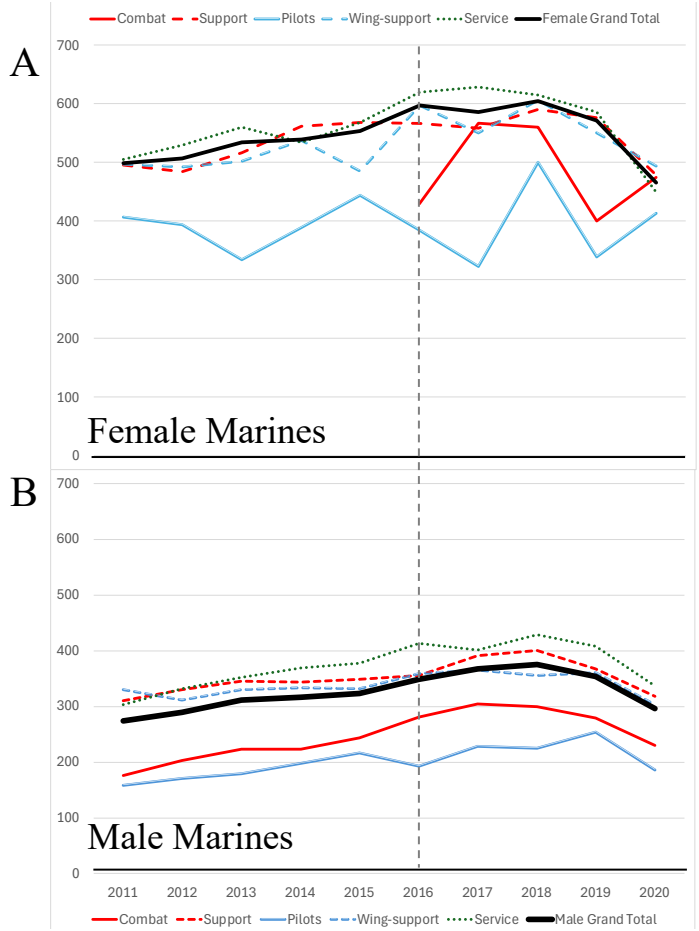
Table 4. Results of the Multivariable Negative Binomial Regression Assessing Sex, Occupation, Integration Period, and Sex-by-Period Interaction on Combined Musculoskeletal Injury Risk, 2011–2020

		RR	95% CI		*p*
			LL	UL	
Sex	Female	**1.99**	**1.78**	**2.23**	**<.001**
Occupation	Ground combat	**0.69**	**0.58**	**0.84**	**<.001**
	Ground combat support	0.94	0.80	1.11	.48
	Aviation	**0.69**	**0.57**	**0.82**	**<.001**
	Aviation support	0.95	0.80	1.12	.54
Period	Post-integration (2016–2020)	**1.21**	**1.08**	**1.35**	**<.001**
Sex-by-period interaction	Female sex, post-integration	Non-significant			
Negative log-likelihood ratio		5449			

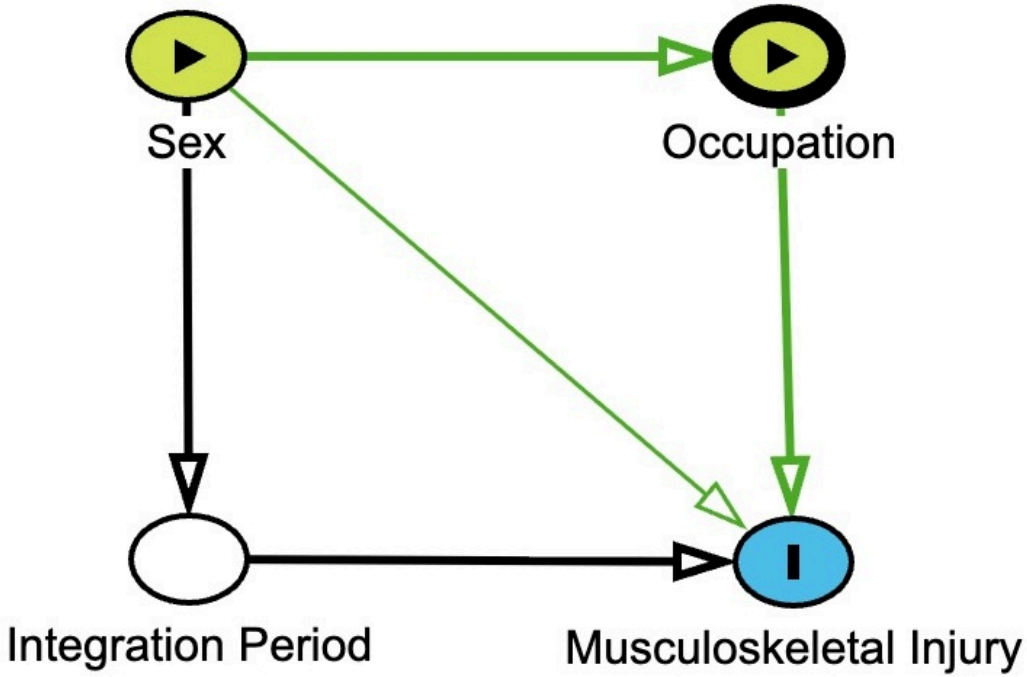
Reference groups: sex (male); occupation (services); period (pre-integration, 2011–2016); sex-by-occupation interaction (male Marines in services occupations); sex-by-period interaction (male Marines during the pre-integration period). RR, relative risk; LL, lower limit; UL, upper limit. Bolded values indicate statistically significant findings.

Supplemental Material

Supplemental Figure 1. Prevalence of musculoskeletal injuries over time in male and female Marines serving in each occupational category and for all occupations combined.



Supplemental Figure 2. Direct acyclic graph detailing the effects of sex and occupation with moderation of integration period on musculoskeletal injury.



Supplemental Table 1. Results of the multivariable negative binomial regression assessing sex, occupation, integration period, and sex by period interaction on lower quarter injury risk in US Marines, 2011-2020.

		Lumbopelvic-Hip				Knee				Ankle-Foot			
		RR	95% CI		*p*	RR	95% CI		*p*	RR	95% CI		*p*
			LL	UL			LL	UL			LL	UL	
Sex	Female	**2.63**	**2.38**	**2.90**	**<.001**	**1.75**	**1.57**	**1.95**	**<.001**	**1.92**	**1.72**	**2.14**	**<.001**
Occupation	Ground combat	**0.71**	**0.60**	**0.83**	**<.001**	**0.61**	**0.51**	**0.73**	**<.001**	**0.64**	**0.53**	**0.76**	**<.001**
	Ground combat support	0.98	0.85	1.13	.79	0.96	0.81	1.12	.58	0.90	0.77	1.07	.23
	Aviation	**0.63**	**0.54**	**0.73**	**<.001**	**0.46**	**0.39**	**0.54**	**<.001**	**0.53**	**0.45**	**0.63**	**<.001**
	Aviation support	1.15	0.99	1.33	.07	**0.85**	**0.72**	**0.99**	**.04**	**0.78**	**0.66**	**0.92**	**.003**
Period	Post-integration (2016–2020)	**1.13**	**1.02**	**1.25**	**.02**	1.05	0.94	1.17	.37	**1.53**	**1.37**	**1.71**	**<.001**
Sex-by-period interaction		Non-significant				Non-significant				Non-significant			
Negative log-likelihood ratio		672.5				650.2				668.7			

Reference groups: sex (male); occupation (services); period (pre-integration, 2011–2016); sex-by-occupation interaction (male Marines in services occupations); sex-by-period interaction (male Marines during the pre-integration period). RR, relative risk; LL, lower limit; UL, upper limit. Bolded values indicate statistically significant findings.

Supplemental Table 2. Results of the Multivariable Negative Binomial Regression Assessing Sex, Occupation, Integration Period, and Sex-by-Interaction on Lower Quarter Injury Risk in U.S. Marines, 2011–2020

		Cervicothoracic				Thoracocostal				Shoulder				Elbow				Wrist-Hand			
		RR	95% CI		*p*	RR	95% CI		*p*	RR	95% CI		*p*	RR	95% CI		*p*	RR	95% CI		*p*
			LL	UL			LL	UL			LL	UL			LL	UL			LL	UL	
Sex	Female	**2.36**	**2.06**	**2.72**	**<.001**	**2.20**	**1.96**	**2.46**	**<.001**	1.00	0.83	1.20	.99	**1.57**	**1.26**	**1.95**	**<.001**	**1.38**	**1.22**	**1.57**	**<.001**
Occupation	Ground combat	**0.77**	**0.61**	**0.96**	**.02**	**0.67**	**0.55**	**0.80**	**<.001**	**0.76**	**0.62**	**0.92**	**.006**	1.15	0.81	1.61	.44	**0.67**	**0.54**	**0.82**	**<.001**
	Ground combat support	0.94	0.76	1.15	.53	1.03	0.87	1.22	.72	1.03	0.86	1.23	.73	0.90	0.66	1.24	.53	**0.78**	**0.64**	**0.94**	**.007**
	Aviation	**1.57**	**1.26**	**1.95**	**<.001**	**1.22**	**1.02**	**1.46**	**.03**	**0.73**	**0.60**	**0.89**	**.002**	1.17	0.81	1.68	.40	**0.46**	**0.37**	**0.56**	**<.001**
	Aviation support	0.98	0.80	1.21	.88	0.98	0.83	1.16	.84	0.94	0.79	1.12	.49	1.00	0.73	1.37	.99	1.07	0.89	1.29	.47
Period	Post-integration (2016–2020)	**1.19**	**1.03**	**1.36**	**.02**	**1.14**	**1.02**	**1.28**	**.02**	1.12	0.96	1.32	.14	**1.48**	**1.19**	**1.84**	**<.001**	1.09	0.96	1.24	.20
Sex-by-period interaction	Female sex: Pre-integration	Non-significant				Non-significant				0.96	0.82	1.12	**.05**	Non-significant				Non-significant			
	Post-integration									**1.26**	**1.06**	**1.51**									
Negative log-likelihood ratio		534.4				544.5				569.0				482.0				561.9			

Reference groups: sex (male); occupation (services); period (pre-integration, 2011–2016); sex-by-occupation interaction (male Marines in services occupations); sex-by-period interaction (male Marines during the pre-integration period). RR, relative risk; LL, lower limit; UL, upper limit. Bolded values indicate statistically significant findings.