

# **Blast Overpressure Effects**

March 2019



# Executive Summary



In 2018, Headquarters Marine Corps Force Preservation Directorate (MCDAPO), in collaboration with the Navy Marine Corps Public Health Center (NMCPHC), initiated a longitudinal health record review of the medical encounter data of 56 service members (SM) from Fox Battery 2/10 (F 2/10), which fired an unusually high number of artillery rounds while deployed from April-September 2017. Initial analysis revealed that these SMs suffered a higher rate of traumatic brain injuries (TBIs) than the rest of the artillery community. When scaled to larger artillery units and future combat against peer/near peer adversaries, this operational tempo could result in the artillery community suffering injuries faster than combat replacements can be trained to replace them. Such human costs should be incorporated into the evaluation of future programs and systems.

Subsequent analysis exploring correlations between combat and several categories of medical conditions and procedures that might be caused by exposure to combat revealed that artillery Marines, regardless of whether they have deployed or not, suffer a higher rate of TBIs and Sensory injuries in comparison to Marines in other MOSs. This difference is exacerbated the more an artillery Marine deploys. Furthermore, in the five months prior to a combat deployment, TBIs suffered by artillery Marines increase by a factor of 4, and once artillery Marines suffer a TBI, they will suffer, on average, 1.2 additional TBIs per year of service after their initial TBI and become more susceptible to spending extended periods of time on Limited Duty. Artillery Marines and those in other combat arms MOSs require, on average, a similar amount of medical care costs (~\$600) for procedures related to BOP injuries each year. This average cost accounts for 13% of total budgeted costs for medical care for the average Marine (\$4,471).

The characteristics of the blast wave that cause TBIs are not fully understood at this time. As such, the Marine Corps should consolidate and fund blast surveillance programs that monitor, record, and maintain data on blast pressure exposure for individual Marines to inform ongoing research and the evaluation of potential mitigation techniques and protective equipment. A 01 February 2019 memo signed by the Deputy Assistant Secretary of Defense for Health Readiness Policy and Oversight outlines six lines of effort that should similarly guide the Marine Corps' efforts to improve the health and readiness of the artillery community.



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# Background



- **Background:** In 2018, Headquarters Marine Corps Force Preservation Directorate (MCDAPO), in collaboration with the Navy Marine Corps Public Health Center (NMCPHC), initiated a longitudinal health record review of the medical encounter data of 56 service members (SM) from Fox Battery 2/10 (F 2/10), which fired an unusually high number of artillery rounds while deployed from April-September 2017. NMCPHC found that all of these service members experienced at least one medical encounter in the year prior to deploying and accumulated a total of 628 outpatient records following the deployment (01 OCT 2017 to 15 MAR 2018).
  - In these post-deployment records, NMCPHC found that about 25% were for conditions or illnesses fitting into a category of illness/injury directly related to overpressure and/or noise exposure.

## **Blast Overpressure (BOP) Injuries:**

Injury caused by the effect of the blast wave on the body. Primary blast injury occurs principally in the gas-filled organs and results from extreme pressure differentials developed at body surfaces. Organs most susceptible include the middle ear, lung, brain, and bowel. This category of injuries includes Traumatic Brain Injuries (TBIs). Many of the long term affects are still not well understood.



# Purpose & Scope



- **Purpose:** At the request of HQMC MCDAPO, NMCPHC conducted an initial screening of the medical records for 56 SMs who deployed with F 2/10 to characterize any injuries associated with a particularly high operational tempo. This work aims to further quantify injuries associated with BOP. *It does not constitute research to establish a direct link between the cause and effect.* The primary objective is to provide a catalyst for further research to inform risk mitigation techniques and protective equipment.
- **Scope:** This study explores correlations between combat and several categories of medical conditions and procedures that might be caused by exposure to combat. These include bone fractures for other combat arms and effects resulting from BOP, such as hearing loss, which is common within the artillery community. MCDAPO examined medical data for 448,980 Active Duty Marines between FY08 – FY18:
  - Deployed artillery Marines assigned to 2/10 and receiving combat pay at the time of high intensity (103 Marines)
  - In 1) Artillery, 2) Other Combat Arms, or 3) Other MOSs further subsetted on A) having deployed and received Combat Pay, B) deployed without receiving combat pay, or C) having not deployed in the individual Marine’s career

Category	Artillery MOS	Other Combat Arms	Other MOS
Combat Pay	5,289	77,070	137,136
Deployed, no Combat	2,065	21,428	42,860
No Deployments (yet)	1,312	28,316	133,401



# Additional Assumptions



- Due to limitations imposed by the Institutional Review Board (IRB), the MCDAPO strips all records of personally identifiable information. Therefore, it is not possible to confirm that all 56 Service Members (SMs) included in the NMCPHC study were part of the 103 Marines deployed with 2/10 during the specified time.
- MCDAPO analysis utilizes NMCPHC health care data; non-Navy provider care is not included.
- MCDAPO uses the Civilian Health and Medical Program of the Uniform Services (CHAMPUS) Maximum Allowable Charge (CMAC) to estimate the costs of procedures. Actual costs incurred by the medical provider are very likely to be significantly higher.
- For the purposes of this study, “combat” is defined as deploying to a combat tax exclusion (CTE) zone and receiving imminent danger pay.
- The exposure rate of BOP injuries used in this study for illustrative purposes was derived from the 17 unique SMs out of the total 56 in the original NMCPHC analysis who were diagnosed following 145 days of combat deployment.



# Methodology



- MCDAPO identifies medical diagnoses using versions 9 and 10 of the International Statistical Classification of Diseases (ICD- 9 and ICD-10) codes captured in:
  - Comprehensive Ambulatory/Professional Encounter Record (CAPER)
  - Standard Ambulatory Data Records (SADR)
  - Standard Inpatient Data Record (SIDR)
  - Theater Medical Data Store (TMDS)
- ICD-9 and ICD-10 codes are grouped into 20+ categories, of which we give special consideration to the following:

ICD Group	Number of Codes Considered	Number of Person-Events
TBI-Specific	31	83,606
Musculoskeletal	745	114,863
Sensory	73	143,485

- The MCDAPO estimates treatments for medical diagnoses from medical procedures using the Current Procedural Terminology (CPT) codes in CAPER and SADR and then map to the Civilian Health and Medical Program of the Uniform Services (CHAMPUS) Maximum Allowable Charge (CMAC) in order to understand costs.
  - **Note:** CHAMPUS costs are maximum allowable costs and not actual costs. They are set below the costs of providing care, resulting in underestimating the true cost of healthcare.
- Similar to ICD codes, CPT codes can broadly be categorized in 10 main areas, of which we give special consideration to (1) Digestive System, (2) Musculoskeletal System, and (3) Endocrine, Nervous, Eye, and Auditory (Enea) System procedures, which broadly support the ICD groups above.
- From these groups, a series of hypotheses tests and other statistical significance tests are utilized to identify differences in medical costs between Marines from different MOSs.

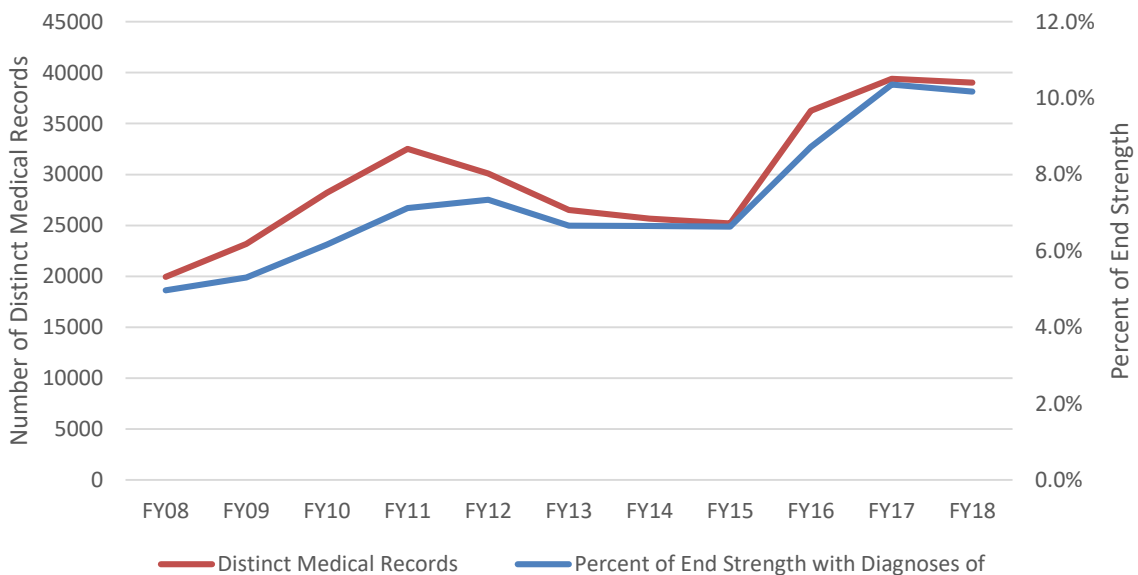


# Impact to the Force



- Since FY15, the Marine Corps has experienced a steady increase in TBI, Sensory, and Musculoskeletal injuries (MSKI).
- Approximately 7.5% of the force experiences at least one TBI, and 3% experience multiple TBIs.
- In FY17, there were over 39,000 unique electronic health records (EHR) with a diagnosis of interest.
- By understanding these effects, the Marine Corps can inform its investment in materiel and non-materiel mitigation strategies to better preserve the force and correspondingly lower costs for both medical care and medical separation.

Number of Distinct Medical Records and  
Percent of End Strength with Diagnoses of Interest



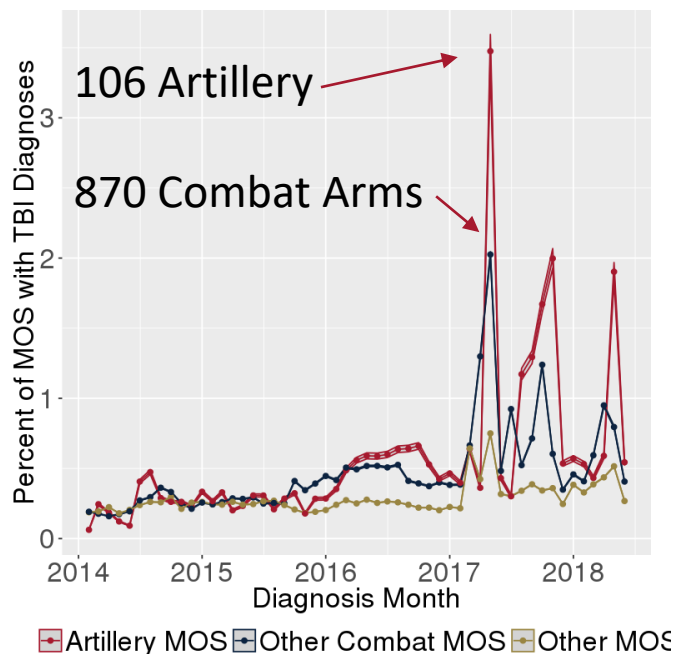
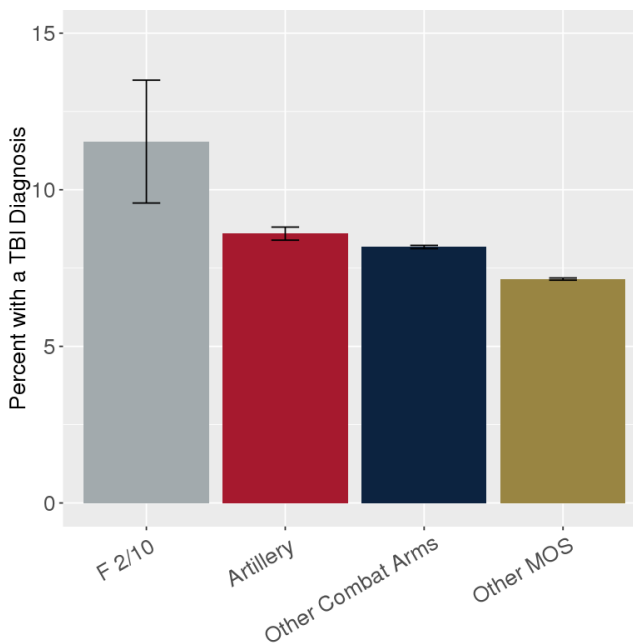




# Traumatic Brain Injuries



- Artillery Marines are diagnosed with TBIs at higher rates than other MOS groups over the course of their Active Duty careers.
- This differential did not manifest itself between 2014 and 2015 when Marines went on fewer combat deployments; however, it becomes prevalent again in 2016 when combat operations escalated.
- The 103 Marines deployed in combat from 2/10 suffered an even higher rate of TBI than the rest of the artillery community.



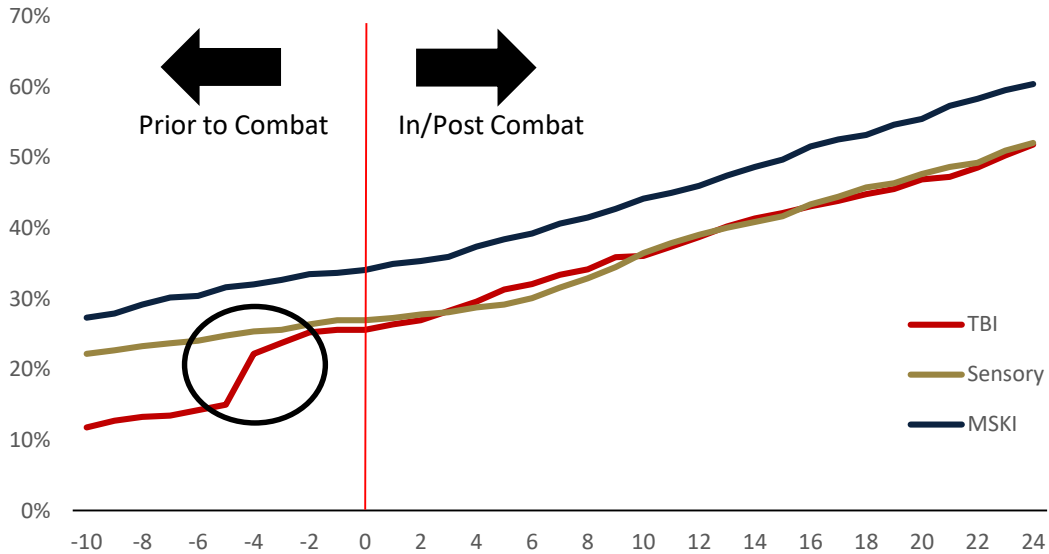
**Traumatic Brain Injuries (TBI):** usually result from a violent blow or jolt to the head or body. Mild TBI may affect brain cells temporarily. More-serious TBI can result in bruising, torn tissues, bleeding and other physical damage to the brain. These injuries can result in long-term complications or death.



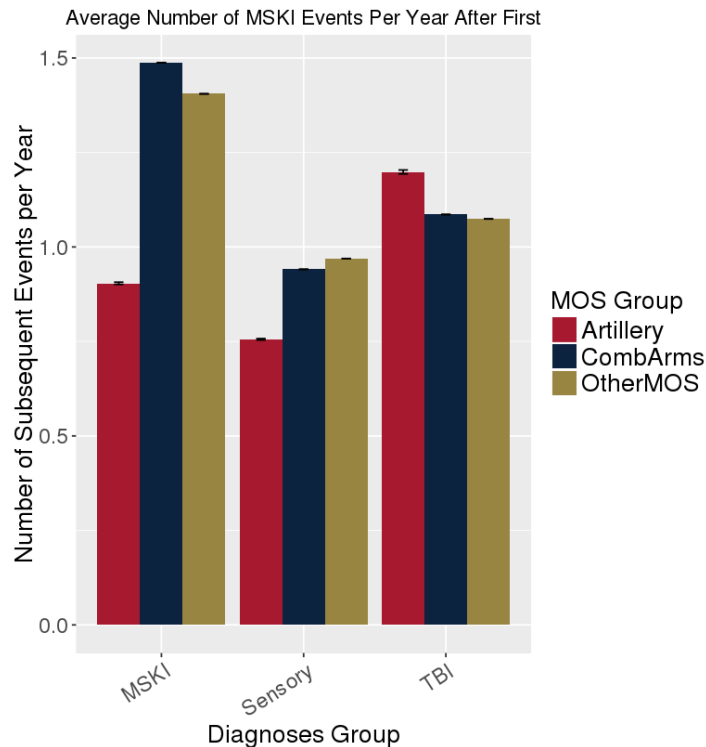
# Increased Vulnerability



First Diagnosis Relative to First Month of Combat



- Over 25% of Marines who go on a combat deployment will have already been diagnosed with a Sensory injury or TBI.
- In the five months prior to a combat deployment, TBIs suffered by artillery Marines increase by a factor of 4.
- Once these artillery Marines suffer a TBI, they will suffer, on average, 1.2 additional TBIs per year of service after their initial TBI.



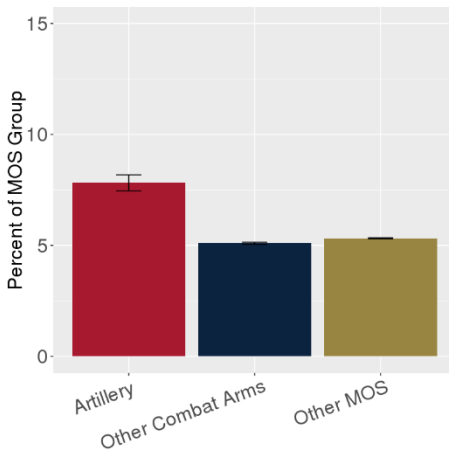


# Non-Deployed Injuries

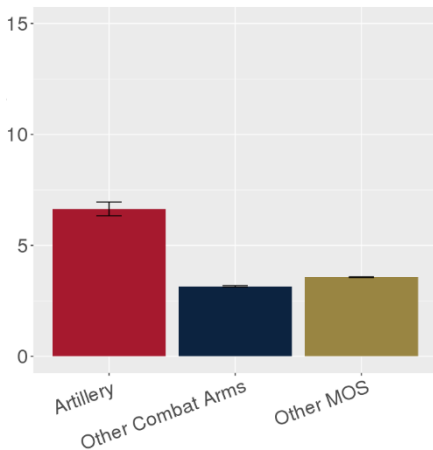


- The diagnoses of interest (Sensory, TBI) vary between occupational fields even among Marines that have never deployed. These differences, however, do not manifest themselves in the diagnoses of other injuries, such as MSKIs.
- Artillery Marines receive a higher number of TBIs and sensory injury diagnoses than Other MOS groups over the course of their Active Duty careers.
- Artillery Marines who have not deployed suffer MSKIs at lower rates in comparison to Marines in Other Combat Arms MOSs and Marines in Other MOS groups who have not deployed.
- This difference remains even after less severe MSKIs (e.g., dislocated fingers, superficial lacerations, etc.) are eliminated from the analysis.

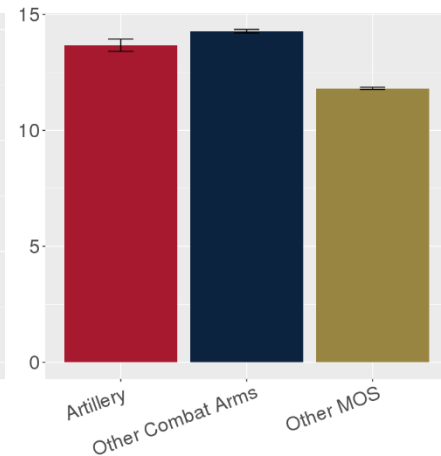
Non-Deployed Marines with Diagnosed Sensory Injuries



Non-Deployed Marines with TBI Diagnoses



Non-Deployed Marines with Musculoskeletal Diagnoses



**Artillery Marines suffer TBIs and Sensory injuries at a higher rate than other Marines.**

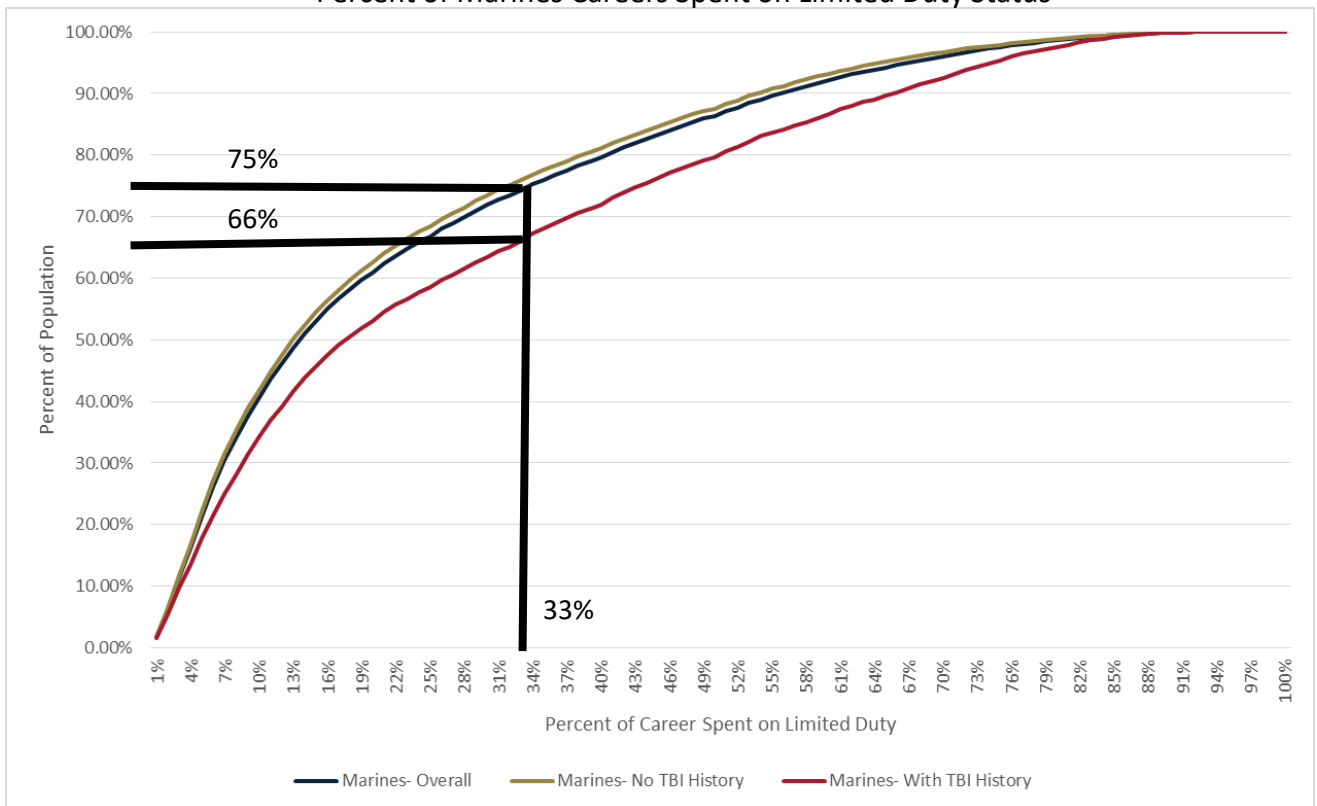


# Limited Duty



- On average, 3.78% of the Active Component was in Limited Duty each month in FY17, which equates to roughly \$584M in personnel costs incurred by Marines on Limited Duty who were not able to fully perform their assigned jobs.
- Of the Marines in a Limited Duty status, 75% spend less than a third of their careers in a Limited Duty status.
- However, for Marines with a history of TBI, only 66% spend less than a third of their careers in Limited Duty status.
- Approximately 14% of artillery Marines are diagnosed with BOP or TBI related injuries at some point in their career, making them more susceptible to spending extended periods of time on Limited Duty.

Percent of Marines Careers Spent on Limited Duty Status

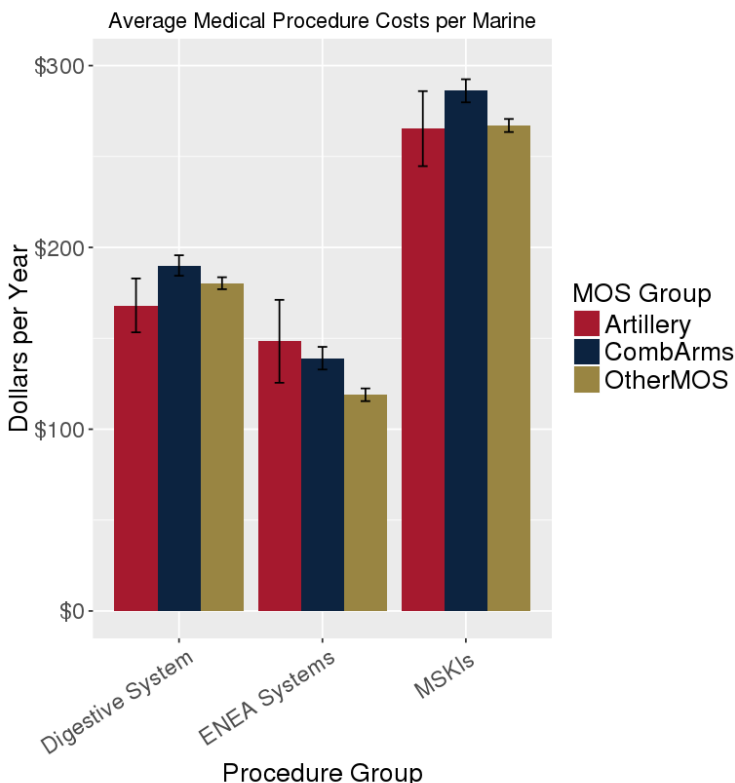




# Medical Costs per Year



- Between FY12-FY17, estimated medical costs for procedures to repair Marines for certain BOP injuries (e.g. Digestive, ENEA, or Musculoskeletal system procedures) totaled, on average, \$31M/year.
- However, these costs do not include Evaluation and Management Services (includes a wide range of services), which exceed \$113M per year on average and totaled over \$146M in FY17 alone.
- Artillery Marines and those in other Combat Arms MOSs require, on average, a similar amount of medical care costs (~\$600) for procedures related to BOP injuries each year. This average cost accounts for 13% of total budgeted costs for medical care for the average Marine (\$4,471).



- Marines in Other MOSs tend to accrue lower costs per year due to MSKI and ENEA procedures than Marines in Combat MOSs.
- Artillery Marines accrue higher costs from ENEA procedures, but this difference is within the confidence interval for Combat and Other MOSs.

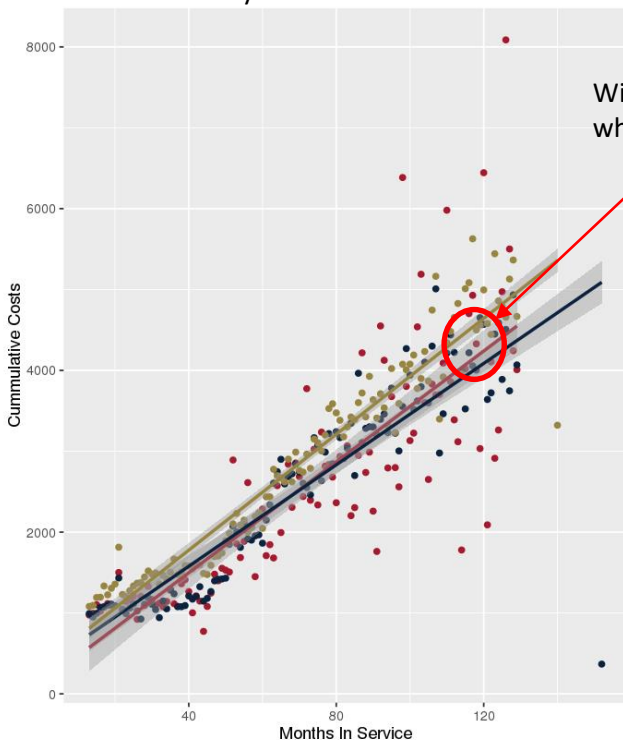


# Medical Costs of Combat

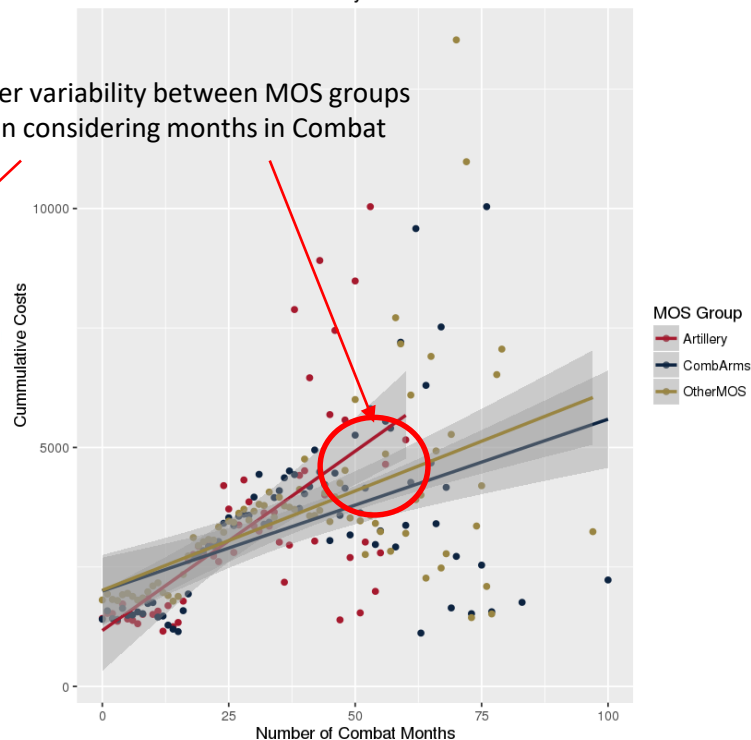


- Medical costs increase over time at a similar rate across the MOS groups. As Marines get older and accrue more time in service, total medical costs do not vary drastically between MOS groups.
- As OPTEMPO (i.e., number of months in which a Marine receives combat pay) increases, medical costs increase at a slightly higher rate for artillery Marines than for those in non-artillery MOSs.

Median Cumulative Medical Costs  
by Time In Service



Median Cumulative Medical Costs  
by Number of Combat Months



**Medical costs for Artillery Marines increase at a higher rate for each month they are in combat as compared all other Marines.**

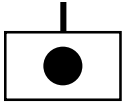


# Operational Impacts


## Estimating Similar Exposure to Larger Units



Although F 2/10's OPTEMPO is unique in recent history, future combat against peer/near peer adversaries may dictate operating at or above this OPTEMPO. As such, we explore the impact this OPTEMPO would have on larger units.




**Standard Artillery Battery**  
per Table of Organization  
T/O 1113G



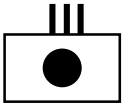
**147 Personnel**  
**6 M777 Howitzers**



**Standard Artillery Battalion**



**447 Personnel**  
**18 M777 Howitzers**



**Standard Artillery Regiment**

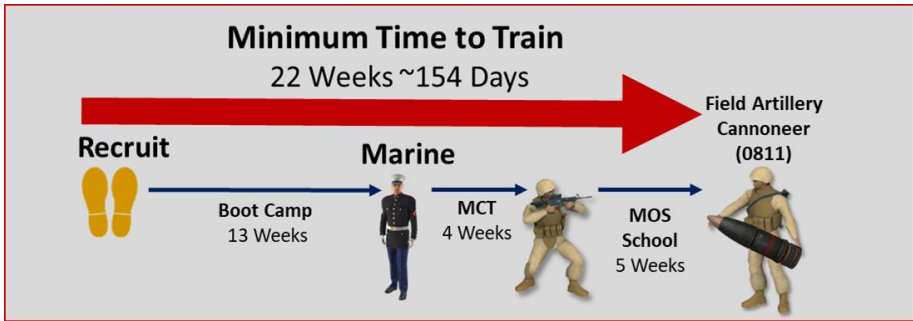


**800 Personnel**  
**36 M777 Howitzers**

- Estimated Full Battery**
- 45 individuals with exposure diagnoses
  - 33,600 rounds fired
  - 232 rounds per day
  - 3,360 rounds at Zone 5

- Estimated Full Battalion**
- 135 individuals with exposure diagnoses
  - 100,800 rounds fired
  - 696 rounds per day
  - 10,080 rounds at Zone 5

- Estimated Full Regiment**
- 240 individuals with exposure diagnoses
  - 201,600 rounds fired
  - 1,390 rounds per day
  - 20,160 rounds at Zone 5



**This OPTEMPO may result in artillery units suffering injuries faster than combat replacements can be trained to replace them.**



# Human System Integration Weapons and Marines



The warfighting capability of artillery units is based on both the equipment and the Marines. F 2/10's high OPTEMPO resulted in cannons becoming unserviceable and Marines being diagnosed with service related injuries.



## Weapon Service Life

- M776 Cannon ~ 2,650 Equivalent Full Charges (EFC) per TM9-1000-202-14
  - F 2/10 OPTEMPO: 8 EFCs per gun per day

***331 Days to condemn cannon***



## Combat Effectiveness of Marines

- Exposure = 1 Marine every 9 days
  - Exposure rate based on F 2/10's total number of unique diagnoses (17 SMs) and total deployment length (145 days)

***Degraded = 18 Days***

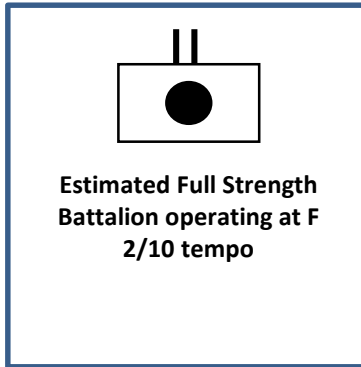
***Combat Ineffective = 48 Days***

**Given F 2/10's OPTEMPO, an M777A2 gun crew would become combat degraded in less than 3 weeks, which is significantly less time than it is estimated to take the howitzer out of service for repairs.**





# Major Combat Operations TBI Considerations



Estimated Full Strength  
Battalion operating at F  
2/10 tempo

### Estimated Full Battalion

- 8 individuals with TBI a diagnosis
- 696 rounds per day



Notional OPLAN  
Artillery Battalion

### Estimated Full Battalion

- 91 individuals with a TBI diagnosis
- 1,832 rounds per day

1,832 rounds per day  
derived from MAGTF Staff  
Training Program (MSTP)  
Pamphlet 4-2 artillery  
battalion Day of Supply  
(DOS)

- Based on planning estimates in an artillery battalion could potentially fire 3x the daily average number of rounds fired by F 2/10 in support of a major combat operation each day.
- Such an OPTEMPO could result in more than 20% of the battalion suffering a TBI.

**In a larger scale operation, more than 90 Marines in an Artillery Battalion could suffer a TBI in support of high sustained rates of fire .**



# Optimizing Warfighter Performance

## Prepare



- **Background:** Education concerning the mitigation of BOP exposure and the identification of BOP symptoms is extremely limited in the artillery community. Current Marine Corps Orders do not address BOP specifically in relation to risk management, and current guidance in *JtRegtO P3570.1F* is somewhat misleading in implying that BOP symptoms manifest themselves immediately. The potentially deleterious effects of sub-concussive blasts over time are seemingly ignored. The artillery community would benefit from more education and research concerning the human costs of BOP, as well as potential mitigation techniques and equipment. A 01 February 2019 memo signed by the Deputy Assistant Secretary of Defense for Health Readiness Policy and Oversight outlines the following six lines of effort that should similarly guide the Marine Corps' efforts to improve the health and readiness of the artillery community.




Line of Effort	Objective
<b>Research</b>	Develop a research strategy and plan of action focused on promoting warfighter brain health and countering TBI.
<b>Surveillance and Prevention</b>	Develop a health surveillance program and utilize the established Section 734 (of the NDAA for FY 2018) Workgroup and program structure to formulate a strategy and action plan.
<b>Diagnosis, Treatment, Rehabilitation, and Reintegration</b>	Assess and improve the TBI standard of care, the translation and implementation of research findings into healthcare practices and health policy, access to and improvement of TBI care, and the rehabilitation and reintegration of service members who have sustained a TBI.
<b>Outreach, Education, and Training</b>	Assess and improve communications about, and promoting awareness of, warfighter brain health and surveillance initiatives.
<b>Long Term Effects of TBI</b>	Synthesize current knowledge related to long term and late effects of TBI, as well as mitigation and countermeasures to reduce or eliminate them.
<b>Section 734, NDAA FY 18</b>	Coordinate with established working groups to successfully implement a strategy for the development of a longitudinal medical study on blast pressure exposure of service members in combat and training.



# Optimizing Warfighter Performance

## Prevent/Protect



Category	Status	Future Assessments	Estimated Savings
<p><b>Hearing Enhancement/Protection Headsets</b></p> 	<p>PM ICE will buy 2,640 hearing enhancement/protection headsets for artillery Marines in July 2019 and expects deliveries to begin around October 2019.</p>	<p>Headsets help protect a Marine's hearing but do not improve protection from blast-related TBIs. As the medical community begins to learn more about the characteristics of the blast wave that cause TBIs, begin investigating new helmet materials, shapes, and designs, as well as enhanced body armor possibilities.</p>	<p>Marines with a history of BOP related injuries on average incur nearly \$10M more annually on Auditory Procedures as compared to those without BOP injuries. A 10% reduction in these procedures could save \$1.6M per year in costs.</p>
<p><b>BOP Software Upgrade</b></p> 	<p>PM TAS will field a software upgrade that incorporates a BOP feature that counts BOP points based upon what round/propellant combination is fired. The software provides warnings when the operators reach 80% and 100% of the maximum allowable points in a 24-hour period. This upgrade will be implemented this fall to synch with an AFATDS update.</p>	<p>Not all positions on the gun line are affected equally, and BOP is affected by terrain and weather, making this upgrade rather rudimentary. Fund and consolidate blast surveillance programs that monitor, record, and maintain data on blast pressure exposure for individual Marines. Purchase field expedient diagnostic tools, such as those provided by BrainScope, to facilitate more accurate TBI assessments at the point-of-care.</p>	<p>BrainScope is FDA-approved medical device which aids in the diagnosis of both concussions and TBIs. The commercial cost of each device is less than \$20,000 (the one-time-use disposable EEG net costs less than \$200), and the results can be determined by a medical professional with minimal training. In contrast, CT scanners cost between \$50,000 to \$80,000 and MRI scanners cost at least \$150,000.</p>
<p><b>Evaluate Non-Development Item Purchase of Wheeled Systems</b></p> 	<p>Recently, many foreign militaries have developed and acquired wheeled, self-propelled howitzers due to their mobility, transportability, and reduced maintenance costs. These wheeled systems require fewer operators.</p>	<p>Acquiring wheeled systems will reduce the number of Marines required in the artillery community. Incorporate these potential medical and training cost savings in the evaluation of future systems.</p>	<p>Transitioning to a wheeled system would save approximately <b>\$200K-250K 18FYD per gun crew</b> in manpower costs.</p>



# Current BOP Research



- In April 2018, the DoD Blast Injury Research Program Coordinating Office published an information paper in response to an RFI on wearable blast sensory. The Marine Corps should use this information paper to justify the acquisition of TRL 9 and MIL-STD-810 compliant devices (e.g., the B3 Wearable Blast Sensor) that can monitor an individual Marine's blast exposure level and thus inform ongoing research.
- On 14 February 2018, the FDA approved a blood-based biomarker test for TBI; however, no TRL 9 and MIL-STD-810 compliant devices capable of measuring these biomarkers exist at this time.
- Most recently, on 2 January 2019, the FDA approved the medical device BrainScope (and EEG-based monitor) for multi-modal, multi-parameter concussion assessment. Acquiring and deploying this device to Marines in theater could reduce rates of TBI-related MEDEVACs and Limited Duty status.



# Conclusions



- F 2/10 fired an unusually high number of rounds during its April-September 2017 deployment, resulting in a TBI rate exceeding the rest of the artillery community.
- Further analysis revealed that artillery Marines, regardless of whether they have deployed or not, suffer a higher rate of TBIs and Sensory injuries in comparison to Marines in other MOSs. This difference is exacerbated the more an artillery Marine deploys.
- The characteristics of the blast wave that cause TBIs are not fully understood at this time. As such, the Marine Corps should consolidate and fund blast surveillance programs that monitor, record, and maintain data on blast pressure exposure for individual Marines to inform ongoing research and the evaluation of potential mitigation techniques and protective equipment.
- Develop a more robust POI concerning the effects of BOP exposure, the identification of BOP symptoms, and potential mitigation techniques.
- Ensure human costs are incorporated into the evaluation of programs and systems.



# Questions

