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The 8 January 2020 theatre ballistic missile attack on US soldiers stationed at Al Asad Air Base, Iraq: case series using a concussion subtypes framework to approach a real-world, chaotic blast-related TBI mass casualty event

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ABSTRACT

Objectives This study aims to describe which concussion subtype(s) result specifically from the explosions of theatre ballistic missiles (TBMs) blast waves, an extremely rare occurrence in modern warfare. We provide feedback from using the US military's standard acute concussion screening tool, the Military Acute Concussion Examination version 2, in a deployed, chaotic, real-world environment.

Background Iran launched 27 professionally manufactured TBMs into Iraq on 8 January 2020. Eleven detonated within Al Asad Air Base, exposing approximately 330 soldiers to TBM-blast waves. The concussion subtype(s) resultant from TBM blast-related concussion is not known.

Methods Case series from the Al Asad TBM-blast exposed cohort who evacuated to Landstuhl Regional Medical Center (LRMC), Germany up to 3 months following the attack and were diagnosed with concussion. Around 4 weeks, TBM-blast exposed individuals still present on Al Asad were screened with the Neurobehavioural Symptom Inventory (NSI) and vestibular ocular motor screening (VOMS); positive screens evacuated to LRMC. Data from 8 January 2020 to 7 April 2020 were cross-sectionally analysed.

Results 35/38 patients met criteria for mild traumatic brain injury/concussion. 34/35 were within a 100 m blast radius. Migraine/headache, cognitive and mood/anxiety subtypes were common. VOMS was abnormal in 18/18 tested; 16 deferred due to overt symptoms. The 4-week screen identified nine additional concussed individuals.

Conclusions Among TBM-blast concussion patients, migraine/headache, cognitive, mood/anxiety and likely vestibular/ocular motor subtypes were predominant. Our study supports postconcussion screening that includes both a subjective symptom inventory, for example, NSI, and a performance-based ocular motor/vestibular screening examination, for example, VOMS, to help identify patients who may under recognise or under-report/minimise symptoms.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Which concussion subtypes predominate specifically following exposure to the blast waves of detonated theatre ballistic missiles (TBMs) is not known given the rarity of their use in the modern era. Future iterations of the current US military's concussion screening tool, the Military Acute Concussion Examination version 2 (MACE-2), would benefit from observations from real-world experience using the tool in a deployed, chaotic, blast-related mass casualty event.

WHAT THIS STUDY ADDS

⇒ Among TBM-blast exposed concussed US Army soldiers, migraine/headache, cognitive and mood/anxiety subtypes were common. Several patients had vestibular/ocular motor findings that they did not attribute to the vestibular/ocular motor domain. Our study emphasises the value of including a performance-based vestibular/ocular motor examination in screening for concussion. Positive screens should prompt referral to a medical provider with expertise in diagnosing and managing concussion.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ There was a lack of uniformity from how the MACE-2 was administered by deployed medical providers, at least initially. Reliable, less intimidating, easier to implement performance-based ocular motor screenings measures can be developed. Validating abnormal performance on vestibular/ocular motor screening in patients claiming to be asymptomatic when they were truly concussed is an area of potential research.

INTRODUCTION

Al Asad Air Base in Iraq was occupied by approximately 6000 US military personnel,

Figure 1 Images of the aftermath following the 8 January 2020 theatre ballistic missile attack on Al Asad Air Base, Iraq. (A) Most soldiers sought cover in C-shaped concrete bunkers. Image of bunker before the attack. (B–F) Images of Al Asad Air Base after the attack. All images courtesy of Alan Johnson.

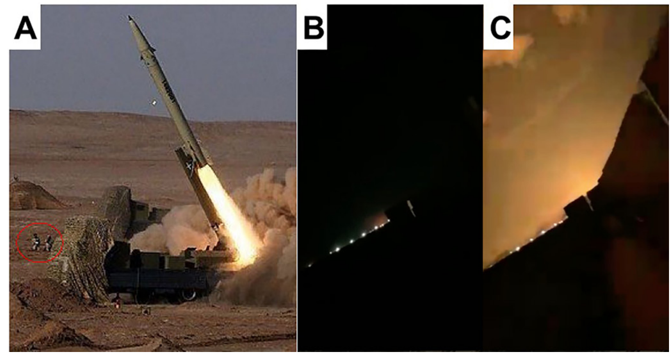

Figure 2 Iran fired 11 theatre ballistic missiles (TBMs) that detonated on Al Asad Air Base, Iraq early on 8 January 2020 exposing US solders to TBM-Blast waves. (A) Stock image of a launching Fateh-313 ballistic missile. Note two human beings (red circle) in the background for perspective. Fateh-style missiles have a length of 8.86 m (30 ft).[4] Image source: Fateh-313-Missile Defense Advocacy Alliance. Accessed 20 December 2020. https://missiledefenseadvocacy.org/missile-threat-and-proliferation/todays-missile-threat/iran/fateh-313. (B, C) Image taken from video (online supplemental video 1) of an Iranian launched theatre ballistic missile while in mid-air just before (B) and then immediately after (C) detonating on Al Asad Air Base, Iraq during the early morning of 8 January 2020. The 11 professionally manufactured Fateh-style and Qiam-style that detonated within Al Asad are believed to have each been carrying explosive payloads of 500–750 kg (1100–1700 pounds).[4] Image courtesy of Alan Johnson; though was not shot by him. The images were shot using the smart phone camera (portrait mode) of an unnamed Department of Defense contractor positioned just outside Al Asad Air Base, Iraq.

contractors and support staff in early January 2020. Iran launched 27 theatre ballistic missiles (TBMs) into Iraq early on 8 January 2020. Once it was determined that TBMs were directed towards Al Asad, the base was evacuated leaving approximately 330 military personnel to continue operations.

Around 01:30 hours, the public address system warned of incoming missiles. Those remaining were ordered to seek cover in mostly above ground C-shaped concrete bunkers (figure 1). Many individuals were still outside trying to get themselves and others into bunkers when the first missiles struck (figure 2, online supplemental video 1). Some bunkers ended up collapsing or catching fire, requiring occupants to flee and seek cover in a new bunker. Some individuals had to do this multiple times. The blasts continued over the next 3–4 hours, exposing many to multiple successive TBM-blast waves. After the bombings stopped, soldiers pulled security, unsure if a ground response from the enemy was to follow. In the wake of the event, they emerged in the night to an environment of smoke, flames, fumes and particulates suspended in air with significant damage to infrastructure.

There were fortunately no casualties and, by outward appearance, no serious bodily injuries. It was not until the day after the attack that service members with postconcussive symptoms started to seek medical attention. Parts of the base would be without electricity for 4–7 days. Within 24 hours, 87 individuals would be diagnosed with traumatic brain injury (TBI), followed by more in the weeks ahead.[1]

Human exposure to the blast waves of professionally manufactured TBMs carrying high explosive payloads is an extremely rare occurrence in modern warfare. The concussion subtype(s) resultant from TBM blast-related concussion have not been described. We present 35 such concussed individuals medically evacuated from Al Asad, Iraq to Landstuhl Regional Medical Center (LRMC), a tertiary US Army hospital in Germany, over a 3-month period following the attack. Which concussion subtype(s) were specifically seen following the blast waves of TBMs is presented. We provide feedback from our experience using the US military's standard acute concussion screening tool, the Military Acute Concussion Examination version 2 (MACE-2), in a deployed, chaotic, real-world environment.

BACKGROUND

From 2000 to third-quarter 2021, there have been 449 026 TBIs among US military services members with 82.3% being mild, that is, concussion.[2] Blast-related TBI is a signature injury from the US conflicts in Iraq and Afghanistan. Most have originated from 'homemade' improvised explosive devices with payloads ranging from small packages/pipe bombs carrying 0.4–2.5 kg (1–5 pounds) to van/SUV/pickup trucks carrying 1800 kg (4000 pounds).[3] A delivery truck, such as the one used to carry out the 1995 Oklahoma City Bombing, can carry a 4500 kg (10 000 pound) explosive payload. The 11 professionally manufactured Fateh-style and Qiam-style that detonated within Al Asad were each believed to have been carrying 500–750 kg (1100–1700 pound) explosive payloads.[4]

Concussion results when biomechanical forces affect the brain causing biochemical, metabolic and physiological dysfunction.[5] These changes are temporary, monophasic and thought to resolve within 1–2 weeks, followed shortly by clinical recovery.[6] Concussed individuals can experience varying symptoms, degree of impairment and recovery trajectories influenced by a variety of risk factors. Trauma/polytrauma patients may have their TBI overlooked altogether.[7 8] An estimated 18.2% of US military combatants in the conflicts with Iraq and Afghanistan experienced mild TBI.[9] Approximately 47% of soldiers who sustained a concussion following their last deployment still reported postconcussive symptoms 3 months later vs 25% of controls without concussion.[10] The effects of concussion can decrease individual or unit effectiveness,[11] leading to increased risk of further injury to the individual.[12 13]

Patients tend to present with one or varying combinations of the following concussion subtypes: vestibular, ocular motor, migraine/headache, cognitive and anxiety/mood.[14] Concussion-associated symptoms include sleep disturbance and neck pain/strain. If not promptly recognised and treated, postconcussive symptoms can persist and evolve into postconcussive syndrome.[6] In postconcussive syndrome, there is a continuation or worsening of symptoms, often due to coexisting and confounding factors not necessarily related to ongoing physiologic brain injury. It can be recognised by symptom recovery that plateaus followed by an up-and-down symptom course. It should be suspected in patients not resolving by 2–3 weeks postinjury. Blast-related concussion is more significantly associated with post-traumatic stress disorder (PTSD) and PTSD-related cognitive impairment compared with non-blast-related concussion.[15]

Postconcussive syndrome pathophysiology has recently been posited as a 'network' problem within the brain.[16] Symptom subtypes co-occur because their connections are strongly interwoven and can activate, amplify and mutually reinforce each other. The 'disease' is their pathological interactions with one another. The brain may emerge and operate 'good enough' for the short term, but overtime in a manner that is maladaptive, resource-intensive and counterproductive. The key to treatment is to dampen down each of the individual symptoms influence on the other to reduce cumulative symptom burden and facilitate natural recovery.[16–18] TBI multidisciplinary care targets these symptoms individually and in the broader context to efficiently and effectively restore lost abilities or acquire new functions/behaviours to replace those lost after injury. Early initiation of clinical care following concussion is associated with speedier recovery.[19]

The current US military concussion screening tool is the MACE-2.[20] Version 2 is showcased by the addition of the vestibular ocular motor screening (VOMS).[21 22] The VOMS both screens for vestibular and oculomotor symptoms and impairment, and monitors response to vestibular/ocular motor rehabilitation. Patients with the vestibular and oculomotor subtypes benefit from active skilled rehabilitation and may be harmed by commonly recommended strict physical and cognitive rest ('cocooning') strategies.[6 23] Vestibular and ocular motor symptomatic patients may only be symptomatic when provoked by stimuli or movement.[24] From a first principles perspective, it is important to acknowledge that a concussed soldier, who does not want to be removed from activity, can simply answer all the screening questions of the current MACE-2 in a manner that secures a negative concussion screen without confirmatory performance-based testing. Their concussion may go unnoticed by the medical establishment resulting in a prolonged recovery/poor outcome.

METHODS

Design and participants

Eligible patients: (1) were 1 of the original 330 individuals on site at Al Asad during the 8 January 2020 TBM attack; (2) were medically evacuated to LRMC, Germany up to 3 months following the attack and (3) received a diagnosis of TBI from one of our TBI medical providers per standard Department of Defense (DoD) guidelines.[25] TBI medical providers included three neurologists, one full-time TBI clinic physician assistant and one physiatrist. Around 4 weeks, TBM-blast exposed individuals still present on Al Asad were screened with the Neurobehavioural Symptom Inventory (NSI).[26] and VOMS regardless of their clinical state. Positive screens were medically evacuated to LRMC for a full evaluation.

Soldiers arrived to LRMC in waves staggered over several weeks based on air evacuation constraints. All patients present on Al Asad for the attack who touched ground at LRMC, for whatever reason, were directed to the TBI Clinic for evaluation with a TBI medical provider. Their TBI medical provider appointments took place at the LRMC Neurology or TBI Clinic. Policy at that time was to complete the MACE-2 if a patient suffered a potential concussion within the past 30 days. The MACE-2 is usually printed out and completed with the patient by a specially trained TBI clinic licensed practical nurse or 68W/medic. Patients are also given a series of questionnaires. All completed questionnaires and the 14-page MACE-2 are then scanned directly into the record.

Manual data abstraction into a Microsoft Access database was completed by one individual (JBH). Data available in AHLTA, the DoD's outgoing outpatient electronic health record, from 8 January 2020 to 7 April 2020 was cross-sectionally analysed. This review of records encompassed care received at US military treatment facilities in Iraq, Kuwait, Germany and the continental USA. Regarding 'alteration of consciousness', if there was a discrepancy between what patient self-reported on the MACE-2 versus what was documented by the TBI medical provider, we went with the provider. Blast distance was self-reported. Many subjects endorsed being exposed to multiple blast waves, so the lowest distance is presented. VOMS was recognised to be positive if it was specifically documented as such. If the down-range provider documented 'MACE negative', even 'MACE-2 negative', it was assumed no VOMS was performed. Though not the original scope of our research, we made several observations pertaining to use of the MACE-2 as the standard concussion screening tool by deployed medical providers in Iraq.

Measures

Measures used are summarised in table 1. The NSI was the main measure we used to inventory postconcussive symptoms.[26] The NSI has been used widely throughout the Veterans Affairs/DoD healthcare system for decades. NSI scores of 3 and 4, severe and very severe, were considered elevated and likely to interfere with performance on deployment. Concurrent anxiety, depression and post-traumatic stress can result in higher reported scores.[27] We used the validity-10 embedded within the NSI to screen for potential invalid responses.[28] The MACE-2 includes the VOMS, a MACE-2 Cognitive Examination and a standard MACE-2 Neurological Examination.[11 20 22] Other questionnaires included: Headache Impact Test version 6 (HIT-6),[29] PTSD-Checklist for The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (PCL-5),[30] Tinnitus Handicap Inventory,[31 32] Epworth Sleepiness Scale.[33] Later, we discuss MACE-2 Neurological Examination findings. Given there was no formal assessment for neck pain/strain, we annotated if it was specifically mentioned in the medical record.

If individuals who met inclusion criteria did not complete a measure, we communicate that by presenting the denominator with an * after it. For example, for a result 'Abnormal MACE-2 Single Leg Stance in 23/32*' would indicate that 32/35 completed the measure, 3/35 did not complete the measure and among the individuals who completed the measure, 32, it was abnormal for 23/32 individuals.

RESULTS

Thirty-eight individuals exposed on 8 January 2020 were evaluated by a TBI medical provider. Thirty-five patients met criteria for mild TBI/concussion. This included two individuals whose concussion was first recognised in Germany. Three did not suffer a concussion. Of 35, 32 were between ages 18 and 34. Other characteristics of our study population are elaborated on in table 2. Given the small sample size and command/media attention this event garnered, information is presented in a manner to protect privacy/mitigate triangulation. There were zero patients with red flag presentations, neurosurgical emergencies or moderate/severe TBIs including penetrating TBIs.

A total of 3/35 had frank loss of consciousness, 33/35 had alteration of consciousness and 19/35 had post-traumatic amnesia. Of 35, 30 were within 60 m, 34/35 were within a 100 m blast radius and 35/35 within 150 m (figure 3). Nineteen patients had MRI brain scans that were unremarkable, 1 patient had a normal non-contrast CT head and 15 patients had no brain imaging. The 4-week screen performed in Iraq identified nine individuals who would later go on to be diagnosed with mild TBI/concussion in Germany.[25] Of nine, seven required skilled TBI rehabilitation. Abnormal MACE-2 Neurological Examination findings included: pronator drift 14/34*, eye tracking 6/34*, grip strength 6/34*, 3/34* pupil abnormalities, word finding difficulty 2/34* and 0/34* speech fluency. Three patients returned to duty after 1–2 weeks of rest without the need for skilled rehabilitation. Two patients completed several weeks of intense outpatient TBI rehabilitation at LRMC before returning to finish their deployment.

The concussion subtypes for our TBM-blast concussed cohort are presented on figure 4 and online supplemental figure 1. Of 35, 6 had positive Validity-10 screens suggesting over-reporting/exaggeration. All validity-10 patients left the warzone within the first 2 weeks following the attack.

Vestibular subtype: VOMS was abnormal in 18/18 with that abnormal VOMS being first identified in Germany in 8/16. VOMS was deferred due to overt symptoms in 16/35 and there was no evidence it was performed in 1/35. MACE-2 Tandem gait was abnormal in 11/32* and MACE-2 Single Leg Stance was abnormal in 23/32*. Elevated scores were seen on NSI Dizziness in 7/35, NSI Balance in 4/35, NSI Coordination in 5/35; excluding Validity-10 patients these become 1/29, 0/29 and 2/29, respectively.

Ocular motor subtype: NSI Vision in 3/35, excluding validity-10 patients these become 0/29. Detailed scores of individual performances on each of the six items of VOMS were not available in the record.

Migraine/headache subtype: A total of 3/35 had a previous migraine history. Elevated scores were seen on NSI Light Sensitivity in 15/35, NSI headache in 24/35, NSI noise sensitivity in 9/35 and NSI nausea in 7/35; excluding validity-10 patients these become 9/29, 18/29, 5/29 and 3/29, respectively. HIT-6 showed headache had a substantial or severe impact on function in 25/31*. Headache was the NSI item most commonly present (34/35) to at least some degree (ie, NSI scores 1 and higher). Of 34, 4 were prescribed either rizatriptan or zolmitriptan within 3 months from the attack.

Cognitive subtype: MACE-2 Cognitive Examination was abnormal in 16/32*. Elevated scores were seen on NSI concentration in 14/35, NSI forgetfulness in 14/35, NSI decision-making in 9/35,and NSI slowed thinking in

Table 1 Measures

Measure	Description	Scoring/interpretation/comments
Neurobehavioural Symptom Inventory.[26] (NSI or NSI-22)	A 22-item self-reported questionnaire that measures perceived postconcussive symptom severity over the previous 2 weeks. The NSI can be used to trend symptom changes over time. The NSI is not intended to diagnose TBI, rather it functions to aid clinicians in characterising the presence and severity of postconcussive symptoms. Each NSI symptom is scored as follows: 0=not a problem at all. 1=occasional, does not affect daily activities. 2=often present, occasionally disrupt activity but can usually continue with some effort. 3=severe, frequently present and disrupts activity. 4=very severe, almost always present, unable to perform at work, school or home.	NSI-22=the sum of all 22 scored items. Item # in parenthesis. Abnormal: items scored 3 or 4. Subtypes: ▶ Vestibular: dizziness^ (1), balance^ (2), coordination^ (3). ▶ Ocular motor: vision^ (6). ▶ Migraine/headache: light sensitive (7), headache (4), noise sensitive^ (9), nausea^ (5). ▶ Cognitive: concentration (13), forgetful (14), decisiveness^ (15), slow thinking^ (16). ▶ Anxiety/mood: anxiety (19), depression (20), irritability (21), frustration (22). Concussion-associated symptoms: sleep disturbance: NSI fatigue (17), NSI sleep (18). Non-categorised items: NSI hearing^ (8), numbness/tingle (10), taste/smell^ (11), appetite (12).
Validity-10 Scale[28]	An embedded scale within the NSI designed to address patient exaggeration/over-reporting. The 10 NSI item scores that are totaled to make up the scale are identified by ^ after the item number.	Abnormal: a patient can be said to have provided an invalid response if their NSI-22 score is >58 (sensitivity 79%, specificity 93%) or Validity-10 score is >22 (sensitivity 81%, specificity 94%).
MACE-2 Vestibular Ocular Motor Screening[22] (VOMS)	Bedside examination used to assess vestibular and ocular motor symptoms and impairment. Participants self-report baseline headache, dizziness, nausea and fogginess on a Likert scale (0=none, 10=severe). They repeat the scale after each of six provocative tests: smooth pursuits, horizontal saccades, vertical saccades, convergence, horizontal/vertical vestibular ocular reflex and visual motion sensitivity. Takes 5–7 min to administer.	The VOMS can be used to trend symptom changes and response to rehab over time. Contraindicated if unstable cervical spine. We generally defer the VOMS in patients who are overtly symptomatic. Abnormal: any score above baseline that increases above baseline following a provocative manoeuvre. Subtypes: ocular motor, vestibular.
MACE-2 Cognitive Exam[11 20]	A 30-point cognitive screen that includes orientation, immediate memory, concentration and delayed 5-word recall.	25–30, normal. Abnormal: ≤24. 68W/Medics are instructed to refer abnormal scores (≤24) to a physician. Subtype: cognitive.
Headache Impact Test Version 629 (HIT-6)	A self-report measure used to stratify headache impact on work, school, home and in social situations.	≤49, little-to-no impact. 50–55, some impact. 56–59, substantial. ≥60, severe. Abnormal: ≥56. Subtype: migraine/headache
PTSD-Checklist for the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition[30] (PCL-5)	A 20-item self-report screen for PTSD.	≤30, normal. 31–34, borderline. ≥34, abnormal. Abnormal: ≥34. A positive or borderline screen would prompt referral to behavioural health to formally diagnose and manage PTSD. Subtype: anxiety/mood.
Tinnitus Handicap Inventory[31 32]	A 25-item self-report measure used to identify and quantify burden from tinnitus.	≤16, no symptoms/slight. 18–36, mild. 38–56, moderate. 58–76, severe. 78–100, catastrophic. Abnormal: ≥58.

Continued

Table 1 Continued

Measure	Description	Scoring/interpretation/comments
Epworth Sleepiness Scale[33]	A self-report measure of sleepiness. Respondents are asked to rate their usual chance of dozing off in eight scenarios.	≤10, normal. 11–14, mild. 15–17, moderate. 18–24, severe. Abnormal: ≥18. Concussion-associated symptom: sleepiness

The study population completed several measures at their initial TBI medical provider appointment when they arrived from Al Asad Air Base, Iraq to Landstuhl Regional Medial Center, Germany.
MACE-2, Military Acute Concussion Examination version 2; PTSD, post-traumatic stress disorder; TBI, traumatic brain injury.

11/35; excluding validity-10 patients these become 8/29, 9/29, 4/29 and 5/29, respectively.

Mood/anxiety subtype: A toal of 12/35 had a previous psychiatric history. Elevated scores were seen on NSI anxiety in 19/35, NSI depression in 10/35, NSI irritability in 16/35 and NSI easily frustrated in 12/35; excluding validity-10 patients these become 13/29, 15/29, 10/29 and 6/29, respectively. PCL-5 screened positive for PTSD in 13/32* and was borderline for 3/32*.

Concussion-associated symptoms/other: Elevated scores were seen on NSI sleepiness in 19/35 and NSI fatigue in 14/35; excluding validity-10 patients these become 13/29 and 8/29, respectively. Severe sleepiness was seen in 1/32*. Neck pain/strain was seen in 11/34. Catastrophic and severe tinnitus scores (≥58) were only seen in 4/27*. Abnormal MACE-2 Neurological Examination findings included: pronator drift in 14 patients, eye tracking in 6 patients, grip strength in 6 patients, pupil abnormalities in 3 patients, word finding difficulty in 2 patients and speech fluency in 0 patients.

DISCUSSION

Our cohort of TBM-blast wave concussed individuals exhibited prominent symptoms from migraine/headache, cognitive and anxiety/mood subtypes. VOMS was used for our downrange screen to decide who to medically evacuate. Care should be taken not to jump to conclusions, such as performance-based vestibular and ocular motor findings are predominant in post TBM-blast concussion due to self-fulfilling prophecy bias. Our study does support the observation that vestibular/ocular motor symptomatic patients can have vestibular/ocular motor symptoms supported by performance-based findings that they do not attribute to the vestibular and/or ocular motor domains.[24] The concussion subtypes for TBM-blast concussion in our cohort were, in our opinion, were what you would expect from concussion in general. We were surprised tinnitus was not more prevalent.

We selected the NSI and VOMS to help screen upwards of 330 TBM-blast wave exposed individuals still present on Al Asad 4 weeks after the attack. We hypothesised that in that group there would be individuals with a personality-type we call the 'conscientious under-reporter'. We define them as truly concussed individuals who will minimise symptoms and/or shun medical attention to avoid being removed from activity. We see conscientious under-reporters regularly in our clinical practice at various stages of their recovery trajectory. They may shun medical attention for a multitude of reasons. These include grit determination to fulfil their duty, not wanting to burden

Table 2 Characteristics of study population

Ages	Sex	Duty status	Pilots
18–25=13 25–34=19 35–44=1 45–54=2	Men=29 Women=6	Active duty=27 National guard=8	7 UAV 1 Helicopter (22.9% of cohort)
Rank		**Medical History**	
Junior enlisted (E1–E6) = 29 Senior (E7/E8/E9, Warrant Officer, Officer)=6		History of TBI=12/35 (34.2%) TBI in previous 12 months=1/35 (2.9%) Psychiatric history=12/35 (34.2%) Migraine history=3/35 (8.6%)	

Characteristics of 35 US Army Soldiers exposed to theatre-ballistic missile blast-waves on 8 January 2020.
TBI, traumatic brain injury; UAV, unmanned aerial vehicle.

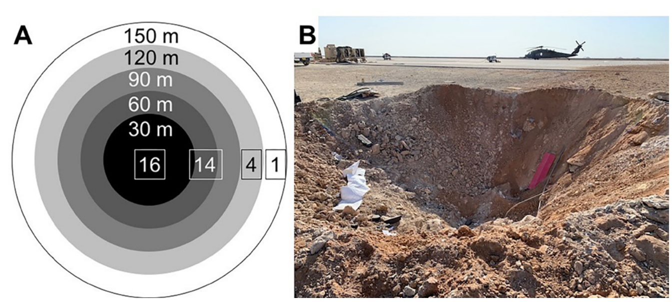

Figure 3 Proximity of our cohort to theatre ballistic missile (TBM) explosion blast radius. (A) Bull's eye diagram showing our cohorts closest distance to an exploding TBM (in 30 m intervals). Note: many individuals were exposed to multiple exploding TBMs, we display the closest distance. Sixteen individuals were within 0–30 m proximity, 14 were within 31–60 m, 4 were within 91–120 m and 1 was within 121–150 m. (B) Large hole left in the ground created by an exploded TBM ballistic missile. Image courtesy of Alan Johnson.

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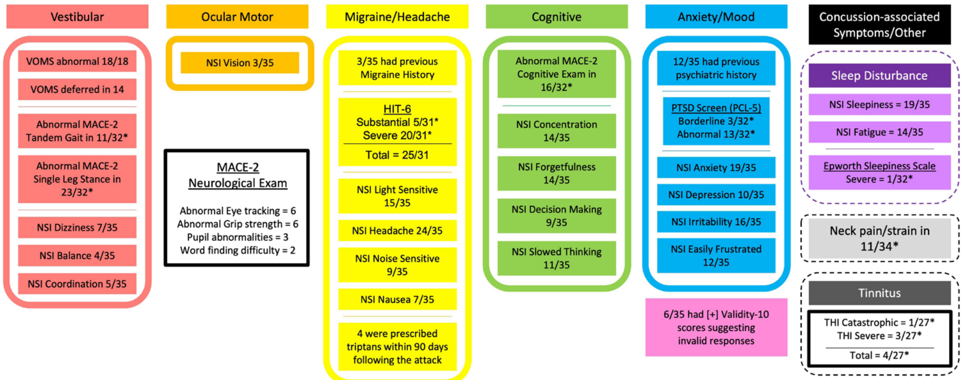

Figure 4 Concussion subtypes of 35 concussed US soldiers exposed to theatre ballistic missile (TBM) blast waves on 8 January 2020. Results from our retrospective chart review using measures described in table 1 are presented. Information is organised by concussion subtypes (vestibular, ocular motor, migraine/headache, cognitive, anxiety/mood) and concussion-associated symptoms (sleep disturbance, neck pain/strain). Tinnitus is also included. For NSI items, the numerator is the number of patients who endorsed a score of 3 or 4. For example, NSI Dizziness 7/35 indicates that 7 of our 35 patients reported scores of 3 or 4. Not all measures were completed by all individuals. We communicate this by presenting the denominator with an * after it. For example, 'Abnormal MACE-2 Single Leg Stance in 23/32*' implies that 32/35 completed the measure, 3/35 did not complete the measure and among the individuals who completed the measure, 32, it was abnormal for 23/32 individuals. HIT-6, Headache Impact Test version 6; MACE-2, Military Acute Concussion Examination version 2; NSI, Neurobehavioural Symptom Inventory; PCL-5, PTSD Checklist for The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition; PTSD, post-traumatic stress disorder; THI, Tinnitus Handicap Inventory; VOMS, Vestibular Ocular Motor Examination.

their teammates by their absence, not wanting to lose combat pay, not wanting to risk exclusion from future unique military assignments/opportunities, not wanting to jeopardise a current special standing such as flight status or as a special force's operator. In our experience, concussed individuals that initially shun care do eventually wind up in a neurology or TBI clinic. They may show up begrudgingly several months or years after a single or repeat concussions. Many are urged to seek care by a loved one or colleague. Often patients self-refer because they notice a change in their performance, even if others do not. Frequently, they are near their military retirement and are now finally ready to address the symptoms. Often patients will come to the clinic just to 'document everything' before they leave the military and want no care. There are those who never seek or receive treatment to consider. The 4-week screen was our effort to identify these conscientious under-reporters and plug them in to early, skilled TBI rehabilitation. Patients in our clinic are usually rehabilitated over several weeks-to-months with the majority being cleared for full duty.

The MACE-2 is the current DoD standard concussion screening tool. When reviewing the records, we recognised that this was not uniformly performed to standard by all downrange medical providers in Iraq at the patient's first medical encounter. The standard was clearly met in 17/33*. It was clearly not met in 6/33: 'MACE-1', 'MACE not indicated'. Unspecified 'MACE', which may or may not have met that standard, was used in 8/33. The LRMC DVBIC Education Coordinator trained up-down-range medical providers in the immediate days following the attack to help correct this gap. Only 2/33 had abnormal VOMS documented at the initial deployed medical provider visit. Of 16, 8 individuals with positive VOMS had that positive VOMS first identified in Germany. Individuals encountered in-person by our team and through record review communicated a clear misunderstanding of how to interpret results from the MACE-2 Cognitive Examination, e.g. achieving a passing score, such as 30/30, was often falsely equated to mean that the patient did not have a concussion.

The unique circumstances of this event set up an opportunity to address the following question: should all acute concussion screening include a performance-based ocular motor screening exam? Our findings show that there were patients who benefited from this strategy. The observation may potentially be generalisable to situations outside of the military, such as competitive sports. It is an issue that warrants further study, especially in scenarios where patients have an incentive to minimise or under-report symptoms.

Limitations

This study involved a retrospective chart review by one individual performing manual data abstraction of several hundred patient encounter notes. Retrospective chart reviews are at risk for bias or confounding errors.

There were several instances where patients had incomplete evaluations, primarily missing questionnaire data. Oculo motor subtype was incompletely evaluated due to a lack of detailed score performances on each of the six examinations comprising the VOMS. In hindsight, we would have liked to include validated screens for prior trauma/childhood adverse events and resiliency.

Our study did not encompass all potentially concussed individuals from the original 330. It overlooked any individual who left Al Asad within that initial 4-week period and anyone on Al Asad who evaded the 4-week screen. We also did not capture the characteristics of any individual who suffered a concussion but spontaneously recovered within 4 weeks without the need to seek medical attention/initiate skilled TBI rehabilitation.

TBM-blast exposure in combat is exceptionally rare so it is reasonable to conclude that our findings are not generalisable. That may be true, but we do strongly believe that the concussion subtype schema we used to respond to this TBI mass casualty event is very generalisable. Our research demonstrates that it can be scaled upward when considering a large group of patients. We knew the cohort involved many drone pilots. The nature of their job indicated to us that they should be scrutinised for ocular motor deficits before returning to full duty. The 4-week screen was successful in ultimately identifying nine additional concussed individuals.[25] Seven were plugged into early, targeted TBI rehabilitative services as a result.

CONCLUSIONS

The concussion subtype framework provides a practical method for approaching individual or large groups of patients following concussion. Among TBM-blast exposed concussed US Army soldiers, migraine/headache, cognitive and mood/anxiety subtypes were common. Several patients had vestibular/ocular motor findings that they did not attribute to the vestibular/ocular motor domain. Our study supports postconcussion screening that pairs both a subjective symptom inventory, for example, NSI, and a performance-based ocular motor/vestibular screening examination, for example, VOMS, to help identify patients who may under recognise or under-report/minimise symptoms. Our findings support performing the VOMS on all potential acutely concussed military service members before confidently determining a concussion screen to be negative.

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Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and and was evaluated by Regional Health Command-Europe Internal Review Board: AABC, Al Asad Blast Cohort, FY20-13. Our research project was reviewed for applicability of human subjects protections regulations and was determined to meet the exempt criteria as determined by the Landstuhl Regional Medical Center (LRMC) Human Research Protections Office (HRPO). 'The only involvement of human subjects, in the reviewed project, falls under the following category identified in 32 CFR 219.104(d) as exempt from the IRB review requirements: Category 4(iii): Secondary research for which consent is not required: Secondary research uses of identifiable private information or identifiable biospecimens and the research involves only information collection and analysis involving the investigator's use of identifiable health information when that use is regulated under 45 CFR parts 160 and 164, subparts A and E, for the purposes of 'health care operations' or 'research' as those terms are defined at 45 CFR 164.501 or for 'public health activities and purposes' as described under 45 CFR 164.512(b). Patient identifiers will be recorded on a master code sheet and the data collection sheet will be deidentified.

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