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Repetitive Low-level Blast Exposure and Neurocognitive Effects in Army Ranger Mortarmen

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ABSTRACT

Introduction:

Occupational exposure to repetitive, low-level blasts in military training and combat has been tied to subconcussive injury and poor health outcomes for service members. Most low-level blast studies to date have focused on explosive breaching and firing heavy weapon systems; however, there is limited research on the repetitive blast exposure and physiological effects that mortarmen experience when firing mortar weapon systems. Motivated by anecdotal symptoms of mortarmen, the purpose of this paper is to characterize this exposure and its resulting neurocognitive effects in order to provide preliminary findings and actionable recommendations to safeguard the health of mortarmen.

Materials and Methods:

In collaboration with the U.S. Army Rangers at Fort Benning, blast exposure, symptoms, and pupillary light reflex were measured during 3 days of firing 81 mm and 120 mm mortars in training. Blast exposure analysis included the examination of the blast overpressure (BOP) and cumulative exposure by mortarman position, as well as comparison to the 4 psi safety threshold. Pupillary light reflex responses were analyzed with linear mixed effects modeling. All neurocognitive results were compared between mortarmen ($n = 11$) and controls ($n = 4$) and cross-compared with blast exposure and blast history.

Results:

Nearly 500 rounds were fired during the study, resulting in a high cumulative blast exposure for all mortarmen. While two mortarmen had average BOPs exceeding the 4 psi safety limit (Fig. 2), there was a high prevalence of mTBI-like symptoms among all mortarmen, with over 70% experiencing headaches, ringing in the ears, forgetfulness/poor memory, and taking longer to think during the training week ($n \geq 8/11$). Mortarmen also had smaller and slower pupillary light reflex responses relative to controls, with significantly slower dilation velocity ($P < 0.05$) and constriction velocity ($P < 0.10$).

Conclusion:

Mortarmen experienced high cumulative blast exposure coinciding with altered neurocognition that is suggestive of blast-related subconcussive injury. These neurocognitive effects occurred even in mortarmen with average BOP below the 4 psi safety threshold. While this study was limited by a small sample size, its results demonstrate a concerning health risk for mortarmen that requires additional study and immediate action. Behavioral changes like ducking and standing farther from the mortar when firing can generally help reduce mortarmen BOP exposure, but we recommend the establishment of daily cumulative safety thresholds and daily firing limits in training to reduce cumulative blast exposure, and ultimately, improve mortarmen's quality of life and longevity in service.

INTRODUCTION

The adverse cognitive and neurological effects of blast exposure have been a prominent focus in military medicine since the introduction of improvised explosive devices and other forms of explosive warfare within armed conflicts in Iraq and Afghanistan. From 2000 to 2020, there were 434,618 service members in the U.S. Military diagnosed with some form of traumatic brain injury (TBI); the majority of which were classified as mild TBI (mTBI) (82.4%).[1] Additionally, in a retrospective cohort study, 66% of TBIs in deployed settings were found to be caused by blasts.[2] To address this issue, traditional research has focused on characterizing the pathophysiology of and establishing preventative measures for injury caused by single, high-level blasts like improvised explosive devices.[3] However, a severely understudied source of blast exposure that also results

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in negative health outcomes is repetitive, low-level blasts (LLBs).[4]

LLBs are blasts with low pressure that typically originate from a service member's own weapon system. Recent reports suggest that occupational exposure to repetitive LLBs may cause subconcussive, neurological injury that cumulatively impacts service member health and readiness.[5] One source of LLB is the mortar weapon system. Mortars are traditionally used for indirect fire and are operated by a crew of three to four service members (i.e., mortarmen) depending on the specific mortar size. The mortar systems used in the U.S. Army are the 60 mm, the 81 mm, and the 120 mm. When a mortar round is fired, explosive charges ignite within the mortar tube, launching the round to its target. This process exposes mortarmen to an LLB every time a round is fired. Currently, there is limited research on the LLB exposure of mortarmen, and, to the best of our knowledge, there are no publications to date on the physiological effects of blast exposure within the mortarmen population.

Blast exposure from a variety of nonmortar LLB sources has been studied, including explosive breaching, heavy weapon systems, and rifles.[6–13] The Carl Gustaf recoilless rifle has particularly gained notoriety for its high blast overpressure (BOP), or maximum blast pressure, resulting in the establishment of daily firing limits in training.[10,14] Studies with the Gustaf and explosive breaching have found that both produce BOPs exceeding 4 pounds per square inch (psi).[7,8,10,11] This is the incident pressure threshold at which the unprotected human eardrum can rupture.[15] While this threshold is not based on the risk of neurotrauma nor on the cumulative exposure of repetitive blasts, it is relevant as it is referenced in most LLB studies and is used by the U.S. Army to calculate the minimum safe distance for explosive breaching.[16]

A study from Kamimori et al. quantifying blast exposure from mortar systems found that the average BOP experienced by the entire 120 mm mortarmen crew exceeded 4 psi.[12] Mortarmen who were observed standing, rather than ducking below the opening of the mortar tube, experienced an individual average BOP of 5-6 psi. While cumulative blast exposure was not quantified in the study, Kamimori et al. hypothesized cumulative blast exposure to be high in the mortarmen population, as they have no firing limits and can fire hundreds of rounds a day. No other publicly available studies have been conducted concerning mortarmen blast exposure or their resulting cognitive or neurological effects.

Despite this lack of research, the cognitive and neurological effects of LLB exposure from explosive breaching have been studied and can provide insight into the mortarmen experience. Explosive breaching has shown reports of increased incidence and severity in symptoms similar to those of mTBI, including headaches, impaired working memory, and sleep disturbance.[17,18] Recent studies have also shown evidence of slower procedural reaction time measured by the Defense Automated Neurobehavioral Assessment (DANA) and less regional gray matter volume captured by structural magnetic resonance imaging scans relative to controls.[7,9] While these results demonstrate the potential for objectively assessing the neurocognitive effects of LLB exposure, most studies still rely on subjective, self-reported symptoms, highlighting the need for a standard, field-ready tool to objectively evaluate blast-related neurocognitive effects in the military.[19]

The use of pupillometry to assess the function of the pupillary light reflex (PLR) has shown potential as a handheld and sensitive neurological assessment tool in populations with blast-related mTBI. Specifically, Capó-Aponte et al. observed significantly slower constriction and dilation velocities and delayed constriction latency in blast-induced mTBI patients, and Truong and Ciuffreda observed smaller initial and end pupil diameters in mTBI patients, both relative to controls.[20,21] These may act as biomarkers for autonomic nervous system function but have yet to be assessed in populations with subconcussive injury from LLB exposure.[22]

To address the limited literature on blast exposure and related neurocognitive effects from firing mortars, we aimed to quantify the LLB exposure of mortarmen and explore the associations of this exposure with positioning, symptoms, and PLR function. This study was conducted in collaboration with the U.S. Army Rangers stationed at Fort Benning during a week-long mortar training exercise and was motivated by multiple anecdotal reports of symptoms from current and former mortarmen. We hypothesized that mortarmen would experience blast exposure and symptoms similar to other military populations with repetitive LLB exposure.

MATERIALS AND METHODS

Participants

This exploratory study was reviewed and cleared as a "process improvement pilot study" by the U. S. Army Special Operations Command Review Board and jointly acknowledged by the Georgia Institute of Technology Institutional Review Board. All participants signed consent forms to participate and provided de-identified demographic information.

This study was conducted over a 6-day period at Fort Benning with the US Army Rangers (**Table S1**). Blast exposure, neurocognitive symptoms, and pupillometry data were collected from mortarmen ($n = 11$) during 3 days of live fire training on both 81 mm and 120 mm mortar systems. Firing days alternated with nonfiring days, during which symptoms and pupillometry data were collected from control subjects who were also rangers but not mortarmen. Six controls participated in the study; however, two controls were retrospectively excluded based on the criteria disallowing controls who were exposed to blasts during the study or diagnosed with any severity of TBI within the year prior to the study. This resulted in the inclusion of only four controls ($n = 4$). Follow-up symptom and PLR measurements were collected 17 days after the mortarmen's last day of firing.

FIGURE 1. Mortarmen positions. Two views of mortarmen firing the 120 mm mortar with positions labeled (AG = assistant gunner, G = gunner, SL = squad leader, AB = ammunition bearer). Firing positions for the 81 mm mortar system are analogous, with the exception of no AB.

Blast Measurements

The Blast Gauge® System (BlackBox Biometrics, Inc., Rochester, NY), Generation 7, was used to collect blast measurement data. These gauges measure both reflected and incident pressure—capturing true environmental exposure—and have been used to measure LLB in numerous other studies.[7–12,23] Three gauges were used per mortarman, located at the head, shoulder, and chest. Gauges were preset to detect all blast pressures above 0.5 psi, their lowest detectable pressure. The mortarmen positions included an assistant gunner (AG), gunner (G), and squad leader (SL) for each mortar, and an ammo bearer (AB) for the 120 mm mortar (Fig. 1). There were also four fire direction centers (FDCs) who oversaw firing of both weapon systems but were generally positioned farther away and not involved in direct firing. All mortarmen wore standard issue and fitted protective gear, including ear protection (PELTOR™ earmuffs), helmets, and body armor with ballistic front and side plates.

Data from the Blast Gauge System was processed in MATLAB (MathWorks, Inc., Natick, MA). For an individual blast event, the Blast Gauge with the highest BOP value from the set of three gauges was used for BOP analysis. Similarly, the Blast Gauge with the highest positive impulse (psi-ms) in a set of three was used for impulse calculations. Positive impulse was calculated using the following equation, where P_n is the $n^{\mathbf{th}}$ pressure recording above atmospheric pressure and Δt is the time between recordings.

$$\sum_{n=1}^{M} P_n \cdot \Delta t$$

Cumulative BOP and cumulative impulse were calculated as the sums of each mortarman's BOP and impulse measurements, respectively, across all firing days. One-sample *t*-tests were performed to compare the average BOP of each mortarman to the 4 psi threshold.

Neurocognitive Symptom Questionnaire

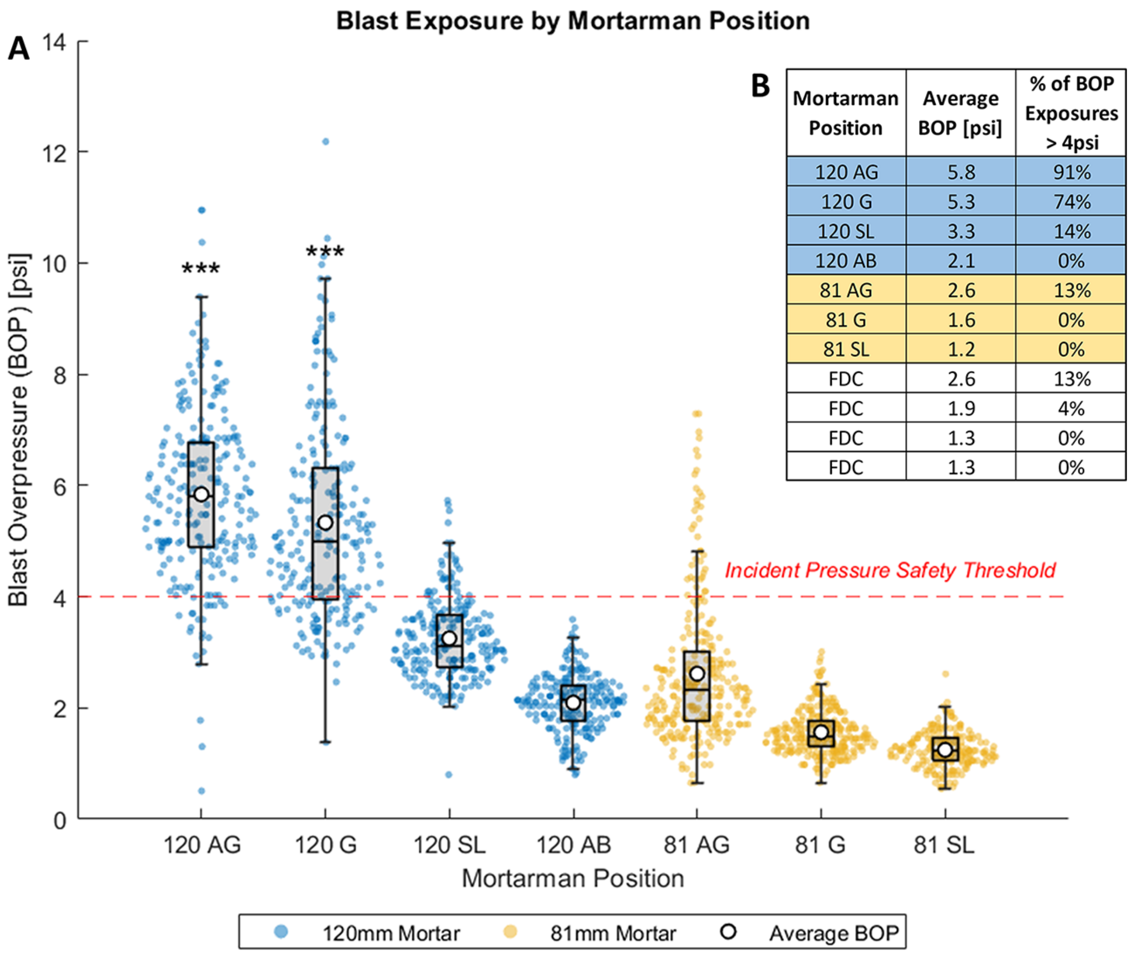
Mortarmen self-reported symptoms immediately before and after firing each day using a modified Rivermead post-concussion symptom questionnaire to rank each symptom from 0 (not experienced) to 4 (a severe problem) (**Fig. S1**).[24] The modifications included 16 additional blast-related questions previously used in other LLB studies.[18,25] Controls also self-reported symptoms at the same times of day as the mortarmen on nonfiring days to ensure consistency in symptoms due to fatigue and other day-to-day factors.

Questionnaire results were analyzed to identify the prevalence of symptoms among all subjects and test the hypothesis that mortarmen experience more symptoms than controls. The most common symptoms were further analyzed by mortarmen classifications: mortar crew and average BOP above or below 4 psi.

PLR Assessments

The PLR-3000 pupillometer (NeurOptics, Irvine, CA) was used to collect PLR measurements during the study.[26] After each subject finished their symptom questionnaire and had adjusted to the ambient light—the natural light outside—for at least 10 minutes, the device recorded static and dynamic pupillary responses to a dim light pulse (10 μW) and a bright light pulse (121 μW) for each pupil. These responses included initial pupil diameter (mm), end pupil diameter (mm), constriction latency (s), constriction velocity (mm/s), maximum constriction velocity (mm/s), and dilation velocity (mm/s).

To determine differences between mortarmen and control pupillary responses, PLR results were analyzed with linear mixed effects models using RStudio (RStudio PBC, Boston, MA). These models allowed for characterizing associations between predictor variables and outcome responses when analyzing repeated measure data by adjusting within-subject variances. Predictor variables included subject type (control or mortarman), pupil measured (left or right pupil), and night measured. Outcome responses are the pupillary responses recorded with each PLR measurement. PLR measurements taken during the day were excluded from analysis, due to the difference in outdoor ambient light between the day and night confounding pupillary responses.



Mortarman Position	Average BOP [psi]	% of BOP Exposures > 4psi
120 AG	5.8	91%
120 G	5.3	74%
120 SL	3.3	14%
120 AB	2.1	0%
81 AG	2.6	13%
81 G	1.6	0%
81 SL	1.2	0%
FDC	2.6	13%
FDC	1.9	4%
FDC	1.3	0%
FDC	1.3	0%

FIGURE 2. (A) Swarm scatter chart displaying all blast events for each mortarman on the 120 mm and 81 mm mortars (AG = assistant gunner, G = gunner, SL = squad leader, AB = ammunition bearer). Overlaid with box plots for each. Subjects with means significantly greater than 4 psi are indicated with $^{***}P < 0.001$. (B) Blast overpressure (BOP) exposure values for all mortarmen, including FDCs (FDC = fire direction center).

Cross Comparison Analysis

Pearson correlations were determined between baseline symptom severity and time served as a mortarman—representing blast history. Baseline symptom results were used for this analysis because they were not influenced by recent blast exposure. Pearson correlations were also calculated to identify associations between pupillary responses and two blast exposure measurements: average BOP and cumulative impulse.

RESULTS

Demographics

All subjects were male rangers with no diagnosed brain trauma within the year prior to this study. Mortarmen and controls did not have a significant difference in time spent as rangers, but they had a significant difference in age ($P = 0.02$), with averages of 23.1 and 28.9 years, respectively (**Table S2**). One control ($n = 1/4$) had prior experience as a mortarman, but the effect of this history was not considered in the scope of this study.

Blast Measurements

During the training week, mortarmen were exposed to a range of 191-268 total blast events on the 81 mm and 216-233 total blast events on the 120 mm. All but three rounds fired were charge 2. The charge refers to the amount of explosive propellant used to fire each round and ranges from 0 to 4, with 4 being the highest charge. The 120 mm G and AG both had average BOPs exceeding 4 psi (Fig. 2A). The G had an average of 5.33 psi, with 74% (172 of 232) of blast events above 4 psi; the AG had an average of 5.84 psi, with 91% (211 of 233) of blast events above 4 psi (Fig. 2B). The 120 mm SL, 81 mm AG, and two FDCs experienced some blast events above 4 psi but still had average BOPs below 4 psi.

The average cumulative BOP for all 81 mm mortarmen was expectedly lower than the 120 mm mortarmen (448 ± 234.3 psi and 951 ± 423.1 psi, respectively). The average cumulative impulse reflected this expectation as well (560 ± 261.7 psi-ms and 788 ± 299.1 psi-ms, respectively). Supplementary material lists all blast exposure calculations and results for all mortarmen, including FDCs (**Table S3**).

Neurocognitive Symptom Questionnaire

The most common symptoms experienced during the week by mortarmen were headaches (91%, $n=10/11$ mortarmen), ringing in the ears (82%, $n=9/11$), forgetfulness/poor memory (82%, $n=9/11$), taking longer to think (73%, $n=8/11$), sleep disturbance (64%, $n=7/11$), and being irritable or easily angered (64%, $n=7/11$). The prevalence of these same symptoms was generally lower among controls: headaches (25%, $n=1/4$ controls), ringing in the ears (50%, $n=2/4$), forgetfulness/poor memory (0%, $n=0/4$), taking longer to think (25%, $n=1/4$), sleep disturbance (75%, $n=3/4$), and being irritable or easily angered (25%, $n=1/4$). Further analysis showed a high prevalence of symptoms in mortarmen regardless of having an average BOP above or below 4 psi. For mortarmen above 4 psi, $n=2/2$ reported headaches, ringing in the ears, and forgetfulness, and $n=1/2$ reported taking longer to think, sleep disturbance, and being irritable or easily angered. For those below 4 psi, all six symptoms were reported by at least $n=6/9$ mortarmen. A similar high prevalence was identified when comparing 81 mm, 120 mm, and FDC mortarmen and showed no preference toward a certain position (**Table S4**). The prevalence and severity of all questionnaire results are provided (**Table S5**).

PLR Assessments

Mortarman had smaller pupil diameters and slower pupillary responses than controls (Table I). Dilation velocity was significantly slower in mortarmen than controls for both dim ($P=0.04$) and bright ($P=0.02$) light pulses. Constriction velocity was also significantly slower in mortarmen for both dim ($P=0.09$) and bright ($P=0.06$) light pulses when increasing the significance threshold ($\alpha=0.10$).

Additionally, constriction velocity was significantly associated ($\alpha=0.05$) with pupil measured for all subjects with both dim ($P=0.005$) and bright ($P=0.03$) light pulses, indicating asymmetry in pupillary response between left and right eyes. Further analysis of mortarmen and control data separately showed that this asymmetry was only significant with mortarmen for the dim light pulse setting ($P=0.01$). No other significant main effects were found. These results were determined using linear models and parameter estimations summarized in the supplementary material (**Tables S6-S8**).

Cross Comparison

Analyses between symptom severity, time as a mortarmen, PLR measurements, and BOP exposure were performed (Fig. 3). For symptom comparison only, the sample size for controls was $n=3$ due to the exclusion of the control who had experience as a mortarman, and the sample size for mortarmen was $n=12$ due to the inclusion of an additional mortarman who reported baseline symptoms but was not available for the rest of the study. A moderate positive correlation was identified when comparing baseline symptom severity scores to time spent as a mortarman and was observed most prominently with forgetfulness/poor memory, being irritable or easily angered, and sleep disturbance. Controls reported none of these baseline symptoms, except for $n=1/4$ controls reporting sleep disturbance at a severity of 1. Pupillary responses negatively trended with blast exposure, indicating lower pupil responsivity with increasing average BOP and increasing cumulative impulse. The initial pupil diameter and end pupil diameter had fair correlations to both average BOP and cumulative impulse while dilation velocity had poor correlations. Graphs for all pupillary responses compared to average BOP, cumulative BOP, and cumulative impulse show similar negative trends (**Figure S2**).

TABLE I. Summary Statistics for Pupillary Light Reflex (PLR)

Pupillary response	Mortarmen ($n=11$) *Mean ± SD*	Controls ($n=4$) *Mean ± SD*	*P*
Dim light pulse (10 μW)			
Initial pupil diameter (mm)	6.29 ± 0.66	6.82 ± 0.89	0.28
End pupil diameter (mm)	3.76 ± 0.48	4.22 ± 0.79	0.25
Constriction latency (s)	0.23 ± 0.03	0.23 ± 0.02	0.85
Constriction velocity (mm/s)	3.15 ± 0.49	3.50 ± 0.35	**0.09**
Max constriction velocity (mm/s)	5.69 ± 2.29	6.05 ± 0.78	0.55
Dilation velocity (mm/s)	1.02 ± 0.28	1.33 ± 0.23	**0.04***
Bright light pulse (121 μW)			
Initial pupil diameter (mm)	6.10 ± 0.68	6.71 ± 0.74	0.16
End pupil diameter (mm)	3.33 ± 0.41	3.73 ± 0.66	0.23
Constriction latency (s)	0.22 ± 0.03	0.24 ± 0.05	0.85
Constriction velocity (mm/s)	3.20 ± 0.48	3.60 ± 0.41	**0.06**
Max constriction velocity (mm/s)	5.99 ± 2.54	6.26 ± 0.53	0.62
Dilation velocity (mm/s)	0.55 ± 0.29	0.87 ± 0.45	**0.02***

Mean and standard deviation (SD) of pupillary responses measured at night from controls ($n=4$) without blast exposure and from mortarmen ($n=11$) immediately after mortar firing. Includes responses from both dim and bright light pulses. Significant values of $P<0.10$ are in bold, and $P<0.05$ is indicated with *.

DISCUSSION

Blast Exposure

Multiple mortarmen had blast exposure exceeding the 4 psi incident pressure safety threshold. This included the AG, G, and SL on the 120 mm mortar and the AG on the 81 mm mortar. Furthermore, the AG and G on the 120 mm mortar, the positions closest to the mortar when firing, had an average

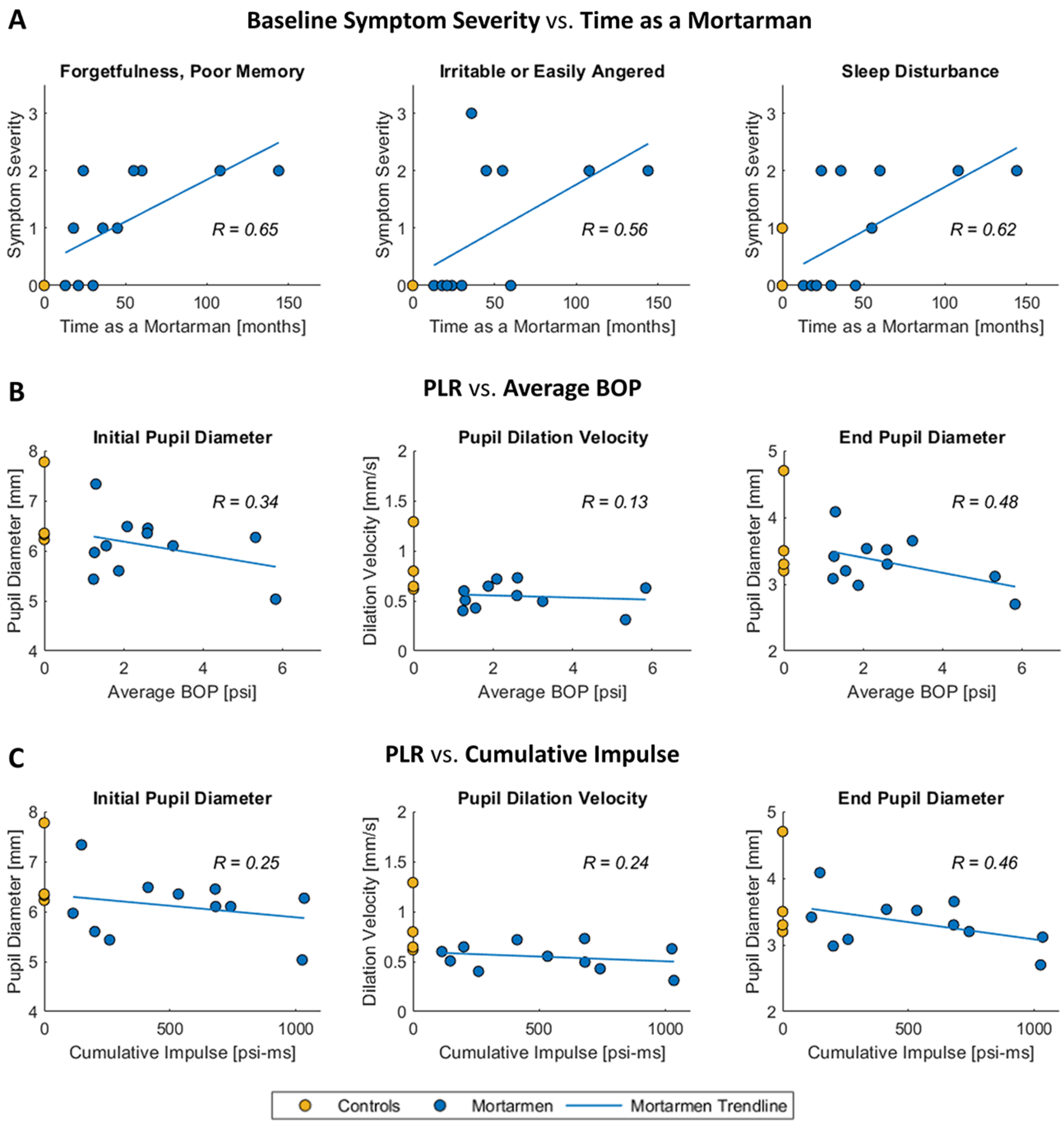


FIGURE 3. Cross comparison of symptoms, blast history, and blast exposure. Trendlines of mortarmen data, excluding controls from calculations. Pearson correlation coefficients displayed as R. (A) Baseline symptom severity scores compared to time as a mortarmen ($n = 3$ controls, $n = 12$ mortarmen). (B) Pupillary light reflex (PLR) measures compared to average blast overpressure (BOP) (B-C: $n = 4$ controls, $n = 11$ mortarmen). (C) PLR measures compared to cumulative impulse.

BOP of 5.8 psi and 5.3 psi, respectively, significantly greater than 4 psi.

Field observations indicated mortarmen positioned farther from the mortar generally experienced less blast exposure. The only exception to this was with the AG and G; despite the Gs being the closest to the mortar, they experienced lower BOPs than their respective AGs, who were slightly farther away. This is inconsistent with Kamimori et al.'s results, in which their Gs had slightly greater average BOPs.[12] Additionally, in their study, mortarmen who stood when in close proximity to the mortar experienced higher BOPs than those who ducked. This occurred with their SLs and range safety officer—an FDC in our study. All FDCs and SLs in our study ducked when near the mortar and experienced lower BOPs, suggesting that ducking may help decrease blast exposure.

The cumulative blast exposure of the mortarmen in our study was also very high. While there are no recommended safety thresholds regarding cumulative blast exposure, the magnitude of exposure experienced by mortarmen can be compared to other sources of LLB. One study observing instructors of shoulder-mounted artillery (e.g., the Gustaf) found that the cumulative BOP experienced over 3 years ranged from 400 psi to 600 psi.[27] The cumulative BOP of most of the mortarmen in our study ($n = 7/11$) reached this range within just 3 days of training, with the highest cumulative BOP at 1,361 psi—more than double the instructors' cumulative exposure. Another study evaluating the cumulative impulse of U.S. Marines over six days of explosive breaching in training found the average cumulative impulse to be 51 psi-ms for students and 43.3 psi-ms for instructors.[6] The exposure of all mortarmen far exceeded these cumulative impulses in just 3 days of mortar firing, with their cumulative impulses ranging from 115 psi-ms to 1,033 psi-ms. Moreover, these cumulative impulses are expected to increase with the additional explosive propellant of charge 3 and 4 rounds commonly used in combat.

Another recently conducted breacher study evaluating blast exposure in conjunction with neurocognitive performance using the DANA Rapid found that breachers with a cumulative impulse greater than 25 psi-ms in 24 hours had slower reaction times in most DANA Rapid subtasks.[7] In our study, all mortarmen exceeded this 25 psi-ms threshold every day, with their daily cumulative impulses ranging from 34 psi-ms to 444 psi-ms. On average, the mortar crews reached this threshold after firing just 12 and 8 rounds on the 81 mm and 120 mm mortars, respectively. These are drastically lower than the respective averages of 89 and 78 rounds fired per day during our study and even lower when compared to the hundreds of rounds fired per day in other training events or combat.

Symptoms

Headaches, ringing in the ears, forgetfulness/poor memory, taking longer to think, sleep disturbance, and being irritable or easily angered were reported by over 60% of mortarmen during the training week. This contrasted with the symptoms of control subjects, who predominantly exhibited ringing in the ears and sleep disturbance. Ringing in the ears, i.e., tinnitus, is common in military service members, and its high prevalence in both mortarmen and controls was expected. The prevalence of sleep disturbance in controls, while unexpected, could be attributed to the ranger lifestyle and altered sleep schedules during training. Another notable result was the high prevalence of symptoms in both mortar crews, even if their average BOP remained below the 4 psi threshold.

The symptoms exhibited by mortarmen expectedly paralleled symptoms experienced by breachers and aligned with some of the symptoms typical of post-concussive and mTBI patients.[28,29] This supports the theory that repetitive LLB can lead to subconcussive injuries, similar to repetitive head impact in sports.[5,30] Increased symptom severity in those with longer history as mortarmen suggests there is an accumulation of repetitive, subconcussive effects over mortarmen's careers, resulting in cumulative neurodegeneration presented as delayed onset and increased severity of post-concussive symptoms.[5,30–34] These delayed effects often go undiagnosed and untreated. Although symptoms exhibited by mortarmen align with mTBI symptoms, a blast-related mTBI diagnosis typically relies on the identification of a single blast event contributing to the onset of symptoms.[35] A diagnosis specific to cases of repetitive LLB exposure would allow for early intervention and treatment during the careers of mortarmen that could improve their long-term health.

Pupillometry

Mortarmen exhibited significantly slower dilation and constriction velocities relative to controls, which is typical of individuals with mTBI or other forms of depressed autonomic neurological function.[20–22] Although not significant, mortarmen also had smaller pupil diameters on average. The older age of controls could have contributed to this lack of significance given pupil size decreases with age.[36] These results are suggestive of systemic neurological issues in mortarmen. The mortarmen also had significant asymmetry in the constriction velocity under the dim light pulse. This has not been observed in mTBI patients but could be a consequence of pupil measurement order.[37] Regardless, the observed PLR differences between blast-exposed mortarmen and controls suggest pupillometry is a promising objective assessment tool for neurological abnormality following blast exposure.

Study Limitations

The major limitation of this study was the small mortarmen and control sample sizes. To conduct our study without interfering with the operational activities of the rangers, only two mortar crews with limited charge ranges could participate in the study. Controls were also limited to available rangers, precluding selection of controls with demographics comparable to mortarmen.

The change in outdoor ambient light before and after firing presented another challenge by causing measurements to vary significantly between day and night, as observed elsewhere.[38] To be a viable neurological assessment tool in outdoors, field environments typical of military training and deployment, we recommend future pupillometer designs better control for measurements taken in varying ambient light settings.

Future Work and Recommendations

Future work to better understand the effect that blast exposure has on mortarmen performance and health could include conducting studies with a similar structure to our study—quantifying blast exposure and objectively measuring neurocognitive effects—to verify our findings. Studies could also explore additional effects of blast exposure not considered in this study, such as longitudinally observing changes in symptomatology and neurocognition over the careers of mortarmen. Alternatively, a retrospective study evaluating the long-term health outcomes of all service members that have been mortarmen could be considered.

In addition to continued research, three areas of action can be considered to reduce mortarmen's blast exposure and improve their long-term health outcomes: behavioral changes, engineering solutions, and safety regulations. Behaviorally, mortarmen who stood farther away from the mortar and ducked generally experienced lower blast exposure; however, this is not a fix-all solution. While it may decrease exposure, ducking mortarmen in this study still experienced high blast exposure and altered neurocognition relative to controls.

Alternatively, blast exposure of mortarmen can be reduced through engineering solutions. Protective gear, for example, could be designed to reduce blast exposure but would still need to prevent the more immediate, life-threatening injuries caused by blunt force or penetrating objects. Another engineering solution is a blast attenuation device (BAD), which extends from the opening of a mortar and reduces the average BOP of mortarmen. In this study, the 81 mm mortar had a BAD but the 120 mm mortar did not. Our results of high symptom prevalence and decreased PLR function among the 81 mm mortarmen suggest that the BAD by itself is not enough to drastically improve health outcomes for mortarmen.

Last, safety regulations can be implemented such as pressure safety thresholds and firing limits. Safety thresholds based on cumulative blast exposure and true environmental exposure—including both incident and reflected pressure—are needed for mortars and other repetitive LLB sources. Based on these thresholds, firing limits in training could be established for mortars like they have been for other weapon systems with repetitive LLBs.[14] Setting daily firing limits in training based on a daily cumulative impulse threshold, like that described in LaValle et al., would effectively decrease mortarmen's high cumulative blast exposure. These limits could be conservative and set for entire mortar crews. Alternatively, due to the highly variable exposures experienced by each mortarman, daily limits could be set for each individual mortarman based on cumulative exposures measured by wearable blast gauges. While establishing firing limits may raise concerns for reduced mortarmen proficiency, the addition of a mortar simulator in training could provide hands-on practice of loading rounds and realigning the sights after the mortar is "fired"—all without any blast exposure.[39]

While all discussed solutions in this paper could be pursued, we recommend this final approach of safety regulations be considered immediately by military leadership to reduce mortarmen blast exposure, with the ultimate goal of extending mortarmen careers and improving their health outcomes during and after service.

CONCLUSION

Mortarmen are exposed to repetitive, LLBs that result in high cumulative blast exposure. This coincides with altered neurocognition relative to controls, suggesting subconcussive injury occurs in mortarmen even with average BOP exposure below the 4 psi safety threshold. While this study had a small sample size, results demonstrate a concerning health risk that requires additional study of the mortarmen population. We recommend that daily cumulative exposure safety thresholds and daily firing limits be established for Army Ranger mortarmen and translated to other mortarmen populations following additional study.

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SUPPLEMENTARY MATERIAL

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CONFLICT OF INTEREST STATEMENT

None declared.

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