A Full-Scale Evaluation of Lightweight Personal Protective Ensembles for Demining in Providing Protection Against Blast-Type Anti-Personnel Mines, by Dr. A. Makris and J. Nerenberg (4.2)

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Introduction

A wide range of equipment, in the form of helmets, vests, aprons and trousers, is currently in use around the world to protect deminers against the effects of AP mines. Significant variations exist in terms of the level of protection afforded, operational usefulness, quality of manufacturing and cost of each of these components. To date, there have been limited studies undertaken to systematically and quantitatively assess the effectiveness of the different protective components applied to both the civilian and military demining theaters. This study summarizes the efforts of numerous full-scale test series carried out in 1999, with particular emphasis on quantifying the protective performance against blast AP mines of selected concepts of humanitarian demining ensembles. It was also possible to assess aspects of the blast and related fragmentation resistance of individual components.

To this effect, full-size human surrogates have been used in the form of instrumented anthropomorphic mannequins. In order to provide meaningful and reproducible data, in the context of explosive blast experiments, it was necessary to devise a "blast resistant" test setup, which permitted realistic experiments to be conducted. No systematic studies were conducted to date involving instrumented human surrogates exposed to a wide range of blast AP mine threats, and the relative protection afforded by different demining protective kits had not been quantitatively evaluated. For this purpose, advanced positioning rigs were developed and constructed by Med-Eng Systems (MES), which permitted the mannequins to be accurately and reproducibly supported in various common demining positions. The mannequin, dressed in a particular protective ensemble and configured in the desired position, was suspended at representative field operating distances from a (simulated or actual) mine, as deduced from measurements taken from deminers.

The HDE Demining Ensembles (by MES) were extensively tested along with a range of helmets and customized full-faced visors under development, including some based on the military PASGT-style, hardhats and sporting helmets. To simulate equipment sometimes deployed by armies involved in demining, a standard issue flak vest, ballistic chaps and a PASGT-style helmet worn with safety goggles were also tested. At the same time, hand protector concepts under development were worn on the mannequin and subjected to representative blast conditions. Pressure sensors and accelerometers mounted on the chest and head of the mannequins were used to evaluate the protective performance of the equipment.

Figure 1: Mannequin placed in crouching position, illustrating versatility of mannequin positioning apparatus. Mannequin donning HDE Demining Ensemble and HDH-2 helmet.

Photo c/o FSE

Experimental Details

In order to perform the experiments for this study, instrumented Hybrid II mannequins were used, representing the 50th percentile North American male (height: 1.75m, weight: 77kg). Such test surrogates were commonly used in the automotive industry for injury assessment of the occupants during crash tests. The joints of the mannequins were tuned prior to each experiment for a relatively realistic initial response when subjected to the blast loading.

Mannequin Positioning Apparatus & Instrumentation

One of the key aspects of testing with mannequins is that in order to obtain repeatable and systematic data, the mannequins must be positioned consistently and realistically. To attain this objective, an advanced positioning apparatus was designed and constructed. The apparatus consists of a large base structure with two supporting arms that can be set at a range of angles from near horizontal to vertical. The arms are far enough apart that a mannequin easily fits between them. On these arms, by means of adjustable brackets, sit two crossbars that connect (by chain links) to the mannequin's hips and shoulders. The crossbars are not rigidly attached to the supporting arms, but they are held in place by the mannequin's weight. Every component on the apparatus can be adjusted by discrete amounts so that positions can be easily and accurately recreated. The use of small link chains and the movable crossbars allow the mannequins to move freely during the initial blast event, thereby preserving the initial bio-fidelity of the mannequin's response. This method of testing is currently under consideration for use by the Canadian Center for Mine Action Technology (CCMAT).

a)

b)

Figure 2: Mannequin kneeling on one knee, dressed in HDE with Sport helmets and positioned 0.66m between sternum and simulated blast AP mine (200g C4); a)pre-blast (left), b)post-blast (right).

The versatility of the test apparatus allows the mannequins to be placed consistently in a wide variety of typical demining positions, including kneeling on one or two knees, standing, squatting and crouching. Figure 1 illustrates a mannequin placed in a crouching position (prior to a blast), similar to a technician inspecting or excavating a mine. In most tests, two mannequins were utilized in order to obtain two sets of data for each mine blast. Figure 2a shows a typical setup where the mannequins were supported in a kneeling on one knee position, prior to a mine detonation, via means of two separate positioning rigs. For the evaluation of equipment and injury potential performed for this study, the mannequins were all placed in a kneeling on one knee position with their sternums 0.66m to 0.68m from the simulated mine—the typical distance a deminer's sternum would be from a mine while using a prodder about 40cm (+/- 10cm) long, based on actual field measurements (Figure 3).

In order to quantify the performance of the various protective equipment evaluated, each mannequin was instrumented with separate clusters of tri-axial (PCB) accelerometers in the head and chest along with two separate (PCB) pressure transducers for measuring overpressure at the ear and sternum. All instrumentation lines were connected via appropriate power supplies and signal conditioning equipment to a computerized data acquisition system. The sensors were calibrated prior to each test series.

Mine Threats

Since actual AP mines are not readily available, simulated mines were extensively used. These mines consisted of C4 plastic explosive packed snugly into injection molded puck-shaped plastic containers and buried with 1cm of overburden in front of the mannequins. Three sizes of simulated mines were used containing 50, 100 and 200g of C4 chosen to represent a wide range of blast type AP mines. The 200g charge is meant to mimic the effects of the PMN mine, which is among the largest and most proliferate of the blast type AP mines. The 100g charge would approximate the threat of a PMN-2, a PPM-2 or a PMA-2 among others while the 50g charge covers a range of smaller mines, including the PMN-4 or the PMA-3. Actual AP mines were selectively utilized for assessing the overall blast and fragmentation resistance of the protective components. The actual AP mines used were the PMN, the PMN-2, the PMA-1, the PMA-2 and the PMA-3.

Figure 3: Deminer prodding for mine in kneeling position, donning HDE Demining Ensemble, HDH-1 Helmet and prototypical hand protector. Typical distance from sternum to end of prodder is 0.65–0.70m.

Photo c/o FSE

General Observations on Blast Integrity of Components

The HDE Demining Ensemble is comprised of two components—a frontal upper body and groin protection apron and frontal leg protection trousers—designed to overlap and provide continuous frontal protection from the neck to the bottom of the shin. The Basic HDE is constructed of soft and hard ballistic materials in combination with a blast attenuation system over the vital regions of the chest and groin to provide protection from fragmentation, blast overpressure and impact. The Enhanced HDE uses an extra layer of high-density rigid ballistic material on top of the basic layout. Under blast testing, against a range of simulated and actual blast type AP mines (PMA1, PMA2, PMA3 and PMN), the blast integrity of the HDE was adequate in preventing any fragmentation penetration or apparent blast damage from reaching the body. The entire ensemble remained in place over the mannequin for all tests conducted under an extensive range of blast severity. The military flack vest and chaps were only tested with simulated mines and similarly remained in place and unaffected over the mannequins for a much smaller number of tests.

Figure 4: Pictures of helmets tested as part of this study.
a) HDH helmets, versions 1 and 2
b) Sport helmets, versions 1 and 2
c) Hardhat helmets, versions 1 and 2
d) PASGT-style helmet with goggles no full face visor

Several helmet concepts have been designed, all of which employed the helmet as a platform for mounting a full-face fragmentation resistant visor. Three styles of helmets were developed: the HDH1 and HDH2, which utilize a military PASGT-style helmet with an advanced retention system (Figure 4a); the Sport1 and Sport2 helmets, which use a lightweight sporting helmet (Figure 4b); and the Hardhat1 and Hardhat2 helmets based on a construction hardhat—a solution commonly deployed in demining theaters (Figure 4c). These Hardhat solutions were, however, developed by MES and differ substantially from similar commercially available products. Two versions of each style were developed, each employing slightly different concepts in construction and design in order to evaluate a larger number of possible solutions for providing head and facial protection. A commercial PASGT-style helmet with ballistic goggles was also tested (Figure 4d).

From the perspective of blast integrity, the HDH and Sport helmets performed best, as they consistently remained in place over the mannequins' heads and were only once penetrated at the visor (5.7mm). The Hardhat helmets proved to be alarmingly weak and susceptible to failure, even at low blast strength. Due to these results, it is feared that similar hardhat based solutions currently in use in worldwide demining theaters may be providing inadequate protection for at least the upper range of AP mine threats (>100g TNT) encountered. For further discussion on the performance of other lightweight head and face protection concepts, please see [Appendix A, 1]. Alarmingly, the PASGT-style helmet with goggles (no visor) were both ejected by the blast from the mannequin's head for mines containing as little as 100g C4.

Figure 5: Detonation of 100g C4 simulated mine. Mannequin to right of charge placed with sternum at 0.66m from mine.

Photo c/o FSE

Several hand protection concepts have also been developed by MES. They are constructed from rigid and soft ballistic materials assembled in aerodynamic shapes, which can be used in various roles in a demining setting (prodding, detecting, etc.). They have proven themselves in over 150 tests of being capable of stopping fragmentation from the full range of mines tested at close range (as close as 16cm). It seems promising that these systems may be able to save a deminer's hand in the case of an accident, though this assertion needs to be verified through testing involving biological specimens.

Figure 2b shows the post-blast scene after two mannequins, dressed with the HDE, Sport helmets, hand protectors and detachable sleeves, were exposed to a simulated mine containing 200g C4. The overall integrity of the equipment against the threat is clearly visible. For further discussion on the construction and blast integrity of the HDE and the components developed, please see [Appendix A, 2]. Figure 5 is provided to give an indication of the threat during the blast event.

Assessment of Overpressure Injury at the Ear for Different Helmet Systems

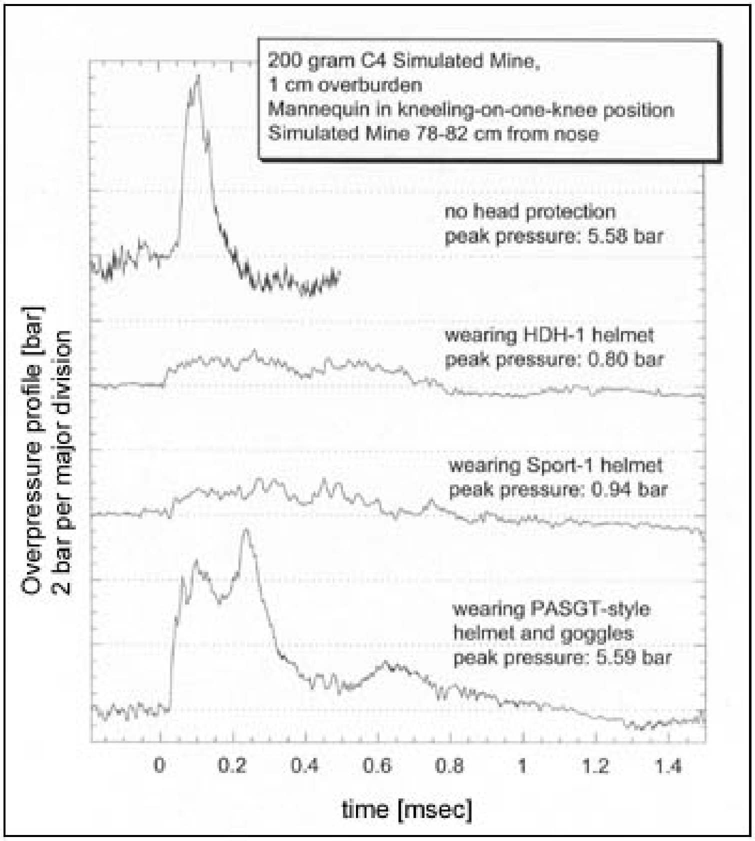

Figure 6: Typical traces of overpressure measured at ear of mannequin from detonation of simulated AP mine.

c/o FSE

The ear is most susceptible to blast overpressure injury compared to other regions of the body. The threshold of eardrum perforation lies at a mere 0.35 bar. An overpressure of one bar will yield 50 percent probability of eardrum perforation while a 95 percent probability of eardrum perforation is predictable for an overpressure of two bar. Damage to the inner ear, which will invariably result in some degree of permanent and irreversible loss of hearing, generally occurs for overpressures above one bar. Though eardrum perforation, or loss of hearing, is not a life threatening injury, it can be a lifelong handicap with potentially detrimental social consequences. Thus, it is important to sufficiently attenuate the blast overpressure level at the ears and to assess the pertinent shielding capabilities of the various helmet systems tested over the full range of blast AP mine threats.

Figure 6 presents the typical pressure traces measured at the ear of the mannequins when exposed frontally to a blast from a simulated AP mine (200g C4) wearing different head protection concepts. The trace obtained for the unprotected mannequin features a sharp rise in pressure generated by the passing blast wave followed by a smooth decay. When the mannequin is dressed with a helmet securely mounted on the head and a well-integrated full-face visor, such as the HDH-1 and Sport-1 helmets, the pressure signal is greatly attenuated in amplitude (< 1 bar) and rate at which the pressure rises. However, if goggles and an open-faced PASGT-style helmet are worn, the peak pressure measured at the ear is comparable to that of wearing no protection (5.6 bar) and is drastically higher than that measured for the HDH-1 and Sport-1 helmets at the same blast conditions. It is proposed that the flared out ear-cups of the PASGT-style helmet design serve to trap the blast overpressure in the absence of a full-face visor and are observed to actually prolong the duration of the pressure pulse considerably (one ms) compared to the unprotected head (0.15 ms).

Figure 7 gives the average value of the peak overpressure measured at the ear of the mannequins for the three charge sizes (50, 100, 200g C4) and for different helmet options mounted on the mannequins. The HDH helmets are consistently the best performers over the range of charge sizes followed by the Sport helmets. The overall performance of the Hardhat helmets is considerably worse. The use of the PASGT-style helmet without a full-face visor results in a higher overpressure than wearing no protection for the full range of AP mine blast conditions tested.

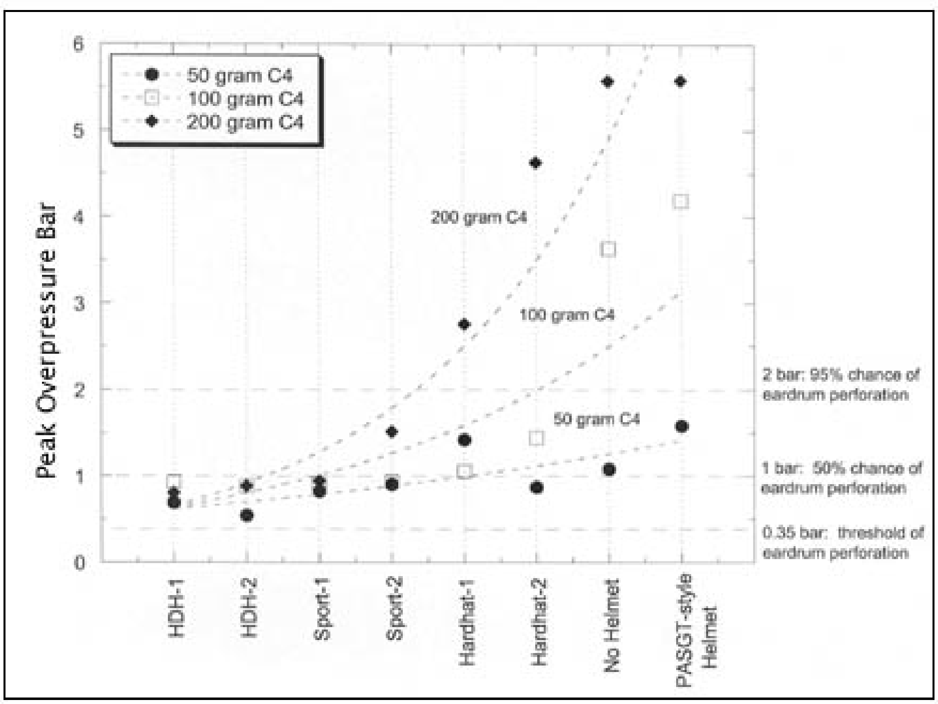

Figure 7: Average peak overpressure measured at ear of mannequins in kneeling-on-one-knee position, facing simulated mines of 50, 100 and 200g C4, buried with 1cm overburden, and 0.66–0.68m from sternum.
c/o FSE

The known thresholds of overpressure for ear injury have been superimposed on Figure 7. For the particular position of the mannequin and distance from the mine, it appears that all helmets tested permitted the overpressure to the ear to rise above the threshold for eardrum perforation (0.35 bar), even for the smallest charge of 50g C4. The overpressure transmitted to the ear when the HDH and Sport helmets were worn did not exceed the 50 percent probability threshold for eardrum perforation (one bar) for all AP mine blast conditions tested. From the full-faced visors, Hardhats did not perform nearly as well, particularly at the 200g C4 condition where measured ear pressures were well in excess of two bar—a 95 percent probability of ear drum perforation. For the unprotected deminer, or the deminer who wears a helmet without a face shield (the PASGT-style helmet/goggles), the overpressures experienced are well above the threshold for a 95 percent chance of eardrum perforation (when facing 100 and 200g of C4). The likely result would be inner ear damage coupled with some form of permanent hearing loss. Though the actual structure of the human ear is not identical to that of a mannequin, the injury levels estimated for the different helmets can still be used as a reasonable guideline.

Head Acceleration Injury Assessment for Different Helmet Systems

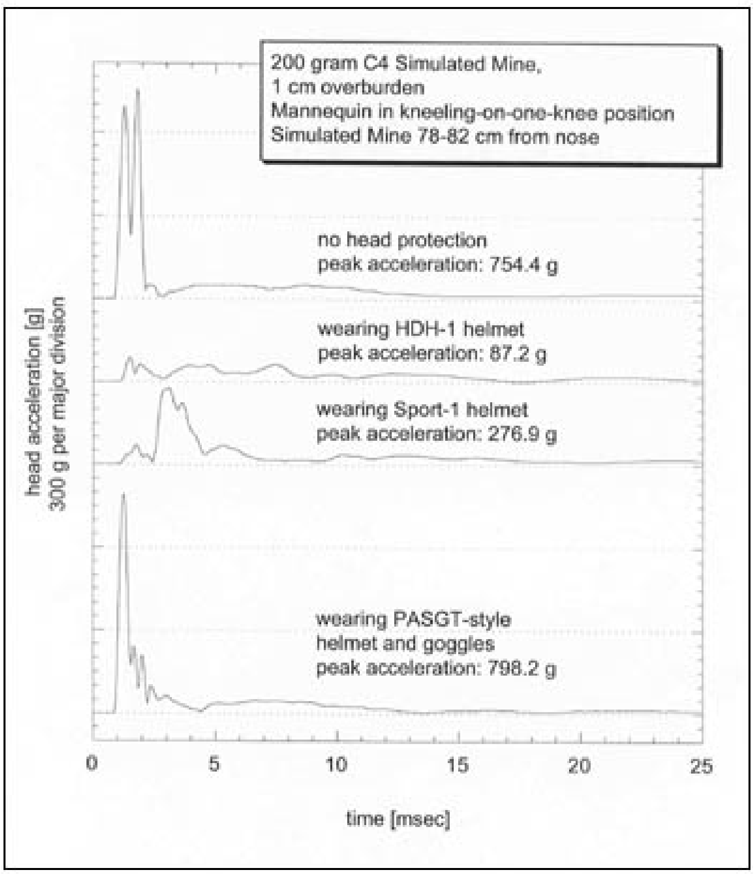

Figure 8: Typical traces of resultant acceleration, as measured at the center of gravity of mannequin's head exposed to blast from simulate d AP mine (200g C4).

c/o FSE

When the head of a victim is subjected to a sudden and violent loading, such as that produced by the blast wave generated from a detonating mine (or other explosive device), a range of injuries from minor to deadly can result. The head region is particularly susceptible to this blast induced acceleration. Figure 8 presents typical resultant head acceleration traces experienced by the mannequin's head wearing different helmets and exposed to the blast from a 200g C4 simulated mine. For the "unprotected" case, a sharp acceleration jump of 754 g's is observed. This value can be greatly reduced when appropriate protective gear is worn, as evidenced from the traces of the mannequin wearing an HDH-1 (87 g's) and Sport-1 helmet (277 g's). Several factors are attributed to this significant reduction in the head acceleration. These factors include the following: the presence of a full-faced visor to aerodynamically deflect the blast wave, a suitable retention system, deflection and energy absorption of the helmet components and an interlocking visor with the top of the chest plate of the HDE. Similar to the results pertaining to ear overpressure, wearing a PASGT-style helmet with no visor results in worse head accelerations than in the case of the mannequin wearing no protection. The flared out ear-cups of this design create a larger profile for the blast to interact and trap the blast, resulting in higher head acceleration.

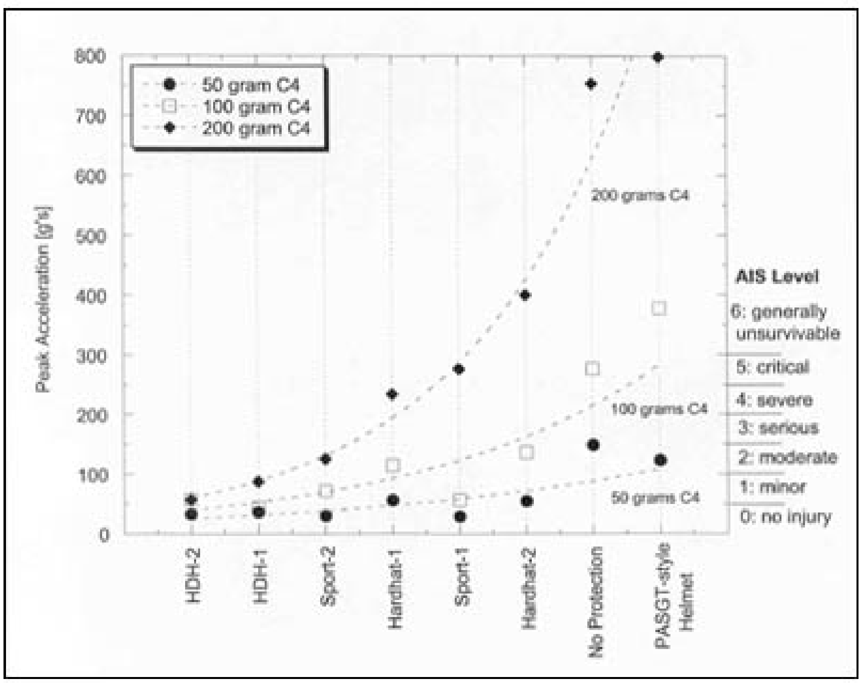

Figure 9: Average peak resultant acceleration, measured at center of gravity of mannequin's head, and AIS head concussion injury scale. Mannequins in kneeling-on-one-knee position, facing simulated mines of 50, 100 and 200g C4, buried with 1cm overburden, and 0.66-0.68m from sternum.

c/o FSE

In comparing the average peak head acceleration measured among the different helmet options across the range of AP mine threat sizes, as presented in Figure 9, it is apparent that the HDH helmets perform best followed by the Sport helmets. The Hardhats, as a group, perform the poorest in reducing the acceleration from the full-faced visor options tested. Facing 100 and 200g of C4, it is apparent that wearing a helmet with no visor is worse than wearing nothing at all from the perspective of frontal blast-induced head acceleration. Figure 9 illustrates that as the explosive threat in the AP mine is increased, the resultant head acceleration experienced also increased for all helmet configurations.

In order to determine the potential for closed head injuries from blast induced acceleration, the 1985 Abbreviated Injury Scale (AIS), which assigns the severity of concussive head injury, has been correlated with peak head acceleration values [Appendix A, 3&4].

Severity of head injury increases with an increase in the peak acceleration experienced by the head, ranging from no injury to dizziness, different levels of unconsciousness and, ultimately, to death. In this relatively simple approach, the injury severity is linked to discrete ranges of peak g's in increments of 50. In reality, the severity of injury does not depend on such discrete steps, as there exists a spectrum of injury probabilities that are possible at each condition depending on numerous factors, including an individual's physical condition, health, age and orientation. Despite its shortcomings, the AIS scale is a good initial approximation in assessing the injury potential that can result and has been plotted on the right vertical axis of Figure 9 alongside the data for the peak head acceleration experienced.

For all head configurations considered, it is observed that the severity of head injury increases with an increase in the explosive content of the AP mine. For a mine containing 50g C4, it appears that wearing any of the tested helmets that incorporate a full-face visor (HDH, Sport and Hardhat) limited the head injury to headaches or dizziness. The unprotected deminer, or one wearing a PASGT-style helmet with goggles and no visor, would not be expected to receive beyond a moderate head injury or brief unconsciousness. The statements presented here only hold true for the conditions used in these tests. Injury potential can differ greatly with a reduction or increase in the separation distance of the deminer from the mine.

The benefit of wearing a full-face visor on a securely mounted helmet is demonstrated for the larger mine containing 100g C4 where only a minor injury would be expected when the HDH and Sport helmets were worn. The Hardhats seem to escalate the head injury to one level higher—moderate—while wearing no facial protection, or the PASGT-style helmet without a visor, may lead to critical or mortal injuries. At 200g C4, the injury potential increases significantly, as the accelerations experienced also increase substantially. Based on just a few tests, only the HDH helmets seem to limit the injury level to the minor level. The Sport helmets keep injuries to within survivable levels, but the Hardhat helmets straddle the generally deadly threshold. If no head protection is worn, or the PASGT-style helmet without a face shield is worn, there is a high probability of a fatal head concussion resulting since the resultant acceleration levels experienced are well above the 300 g's threshold. This result, once again, points to the clear benefit and necessity for a deminer to wear a full-face visor mounted on a stable helmet platform. The data presented above should be treated as a guideline for relative injury assessment based on the different threat conditions and protective equipment utilized. The correlation of head injury with blast induced head acceleration has not yet been validated using instrumented biological surrogates.

Attenuation of Blast Loading (Overpressure and Acceleration) to the Thoracic Cavity

The effectiveness of the flakvest and HDEs in attenuating the thoracic blast loading was investigated through measurements of the transmitted overpressure at the chest wall and gross chest acceleration of the Hybrid II mannequin. Though the different ensembles were tested over the full range of simulated blast AP mines (50-200g C4), only the results for the largest of the threats are presented here. The data for the smaller mines exhibited essentially the same relative trend in attenuation capability by the test candidates except for the smaller peak values of the signals.

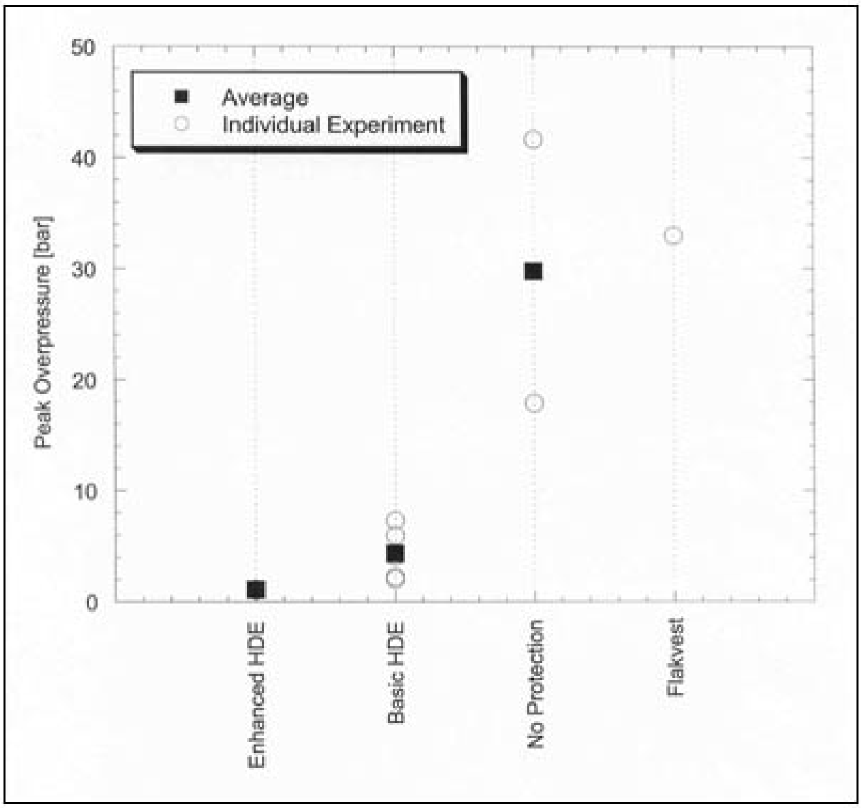

Figure 10: Peak overexposure measured at sternum of mannequins in kneeling-on-one-knee position, facing 200g C4 simulated mine, buried with 1cm overburden and 0.66-0.68m from sternum.

c/o FSE

Figure 10 illustrates the peak overpressures measured at the sternum of the mannequins (kneeling on one knee with sternum 0.66-0.68m from the mine) when facing the simulated mine containing 200g C4. It is immediately apparent that the Enhanced and Basic HDEs led to a substantial reduction in the over pressure transmitted to the chest of the mannequin when compared to the unprotected case. The use of a flakvest, comprised entirely of layers of soft ballistic fabric, did not perform any better than wearing no protection in reducing the transmitted overpressure to the chest wall. In fact, it has been demonstrated that aprons or vests containing soft ballistics alone can actually amplify the overpressure experienced at the chest, depending on the mine threat, separation distance and the particular construction of the protective apparel. The HDE, which has a blast attenuation system comprised of rigid and soft ballistic materials, including an energy absorbing layer, effectively decouples the blast wave for the range of conditions tested and is able to reduce the transmitted overpressure to the thorax, thus reducing the possibility and extent of any injury. For a detailed study of the overpressure measurements for the entire range of blast AP mine threats considered and the implications in terms of injury potential, please refer to [Appendix A, 2&5].

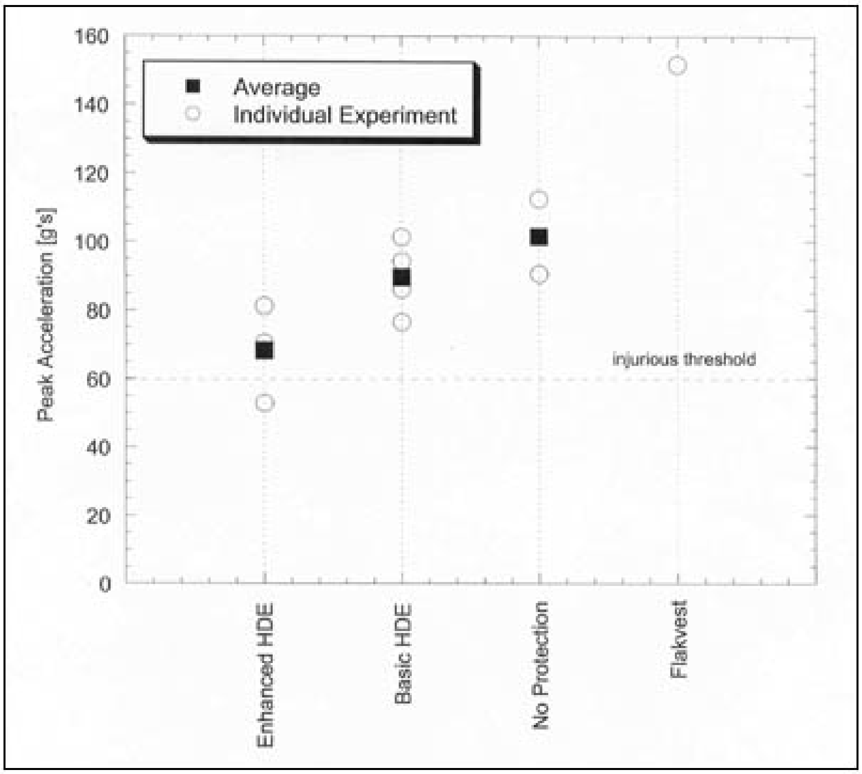

Figure 11: Average peak acceleration measured at chest of mannequins in kneeling-on-one-knee position, facing 200g C4 simulated mine, buried with 1cm overburden and 0.66-0.68 m from sternum.

c/o FSE

The peak resultant acceleration experienced by the chest of the mannequins when facing the 200g C4 simulated mine and dressed in the various protective gear is plotted in Figure 11. The results for acceleration mirror those for overpressure, as the same trend in relative performance is observed. The Enhanced HDE is best able to attenuate blast induced accelerative loading to the chest cavity over the unprotected case followed by the Basic HDE. On the other hand, a flakvest is capable of amplifying the measured chest acceleration. This effect is thought to be a result of the soft ballistic material being accelerated and "slapped" onto the chest cavity. The construction of the HDE, which includes rigid and energy absorbing materials, is able to deflect the incoming blast more effectively and dampen a portion of the resultant accelerative chest loading.

In order to provide a preliminary assessment of the potential for injury resulting from gross chest acceleration, the generally accepted threshold of 60 g's for accelerative chest injury is superimposed on Figure 11. As this value is derived from the automotive industry where the duration of the loading event is typically longer than that associated with the detonation of blast AP mines, the 60 g threshold can be viewed as somewhat conservative. Nevertheless, exceeding the threshold indicates a higher probability that chest acceleration injury will occur. For most of the data where the mannequin faces 200g of C4, the injury threshold is exceeded. The acceleration experienced by the mannequin wearing a flakvest exceeds the injury threshold by approximately 150 percent. Though there are limitations in comparing the response of a Hybrid II chest subjected to blast loading against the injury threshold of 60 g's, the exercise provides an initial approximation for the potential of injury posed to the deminer for the range of conditions tested and permits a relative assessment of the protective effectiveness of different ensembles.

Conclusion

A cross-section of equipment (helmets, aprons, vests, etc.) ncluded as part of personal protective ensembles for demining were systematically tested under controlled but realistic conditions. Actual and simulated blast AP mines in the range of explosive content between 50 and 200g C4 were positioned at representative distances (0.66-0.68m) from the sternum of a prodding deminer kneeling on one knee. Through the use of mannequins, it was possible to provide a quantitative evaluation of the effectiveness of the different equipment for the entire range of blast threats. It was necessary for MES to design special "blast resistant" positioning rigs, which permitted the surrogates, dressed in the different protective apparel, to be reproducibly positioned at the desired distance and configuration. An injury assessment was also made possible by relative comparisons of measurements of overpressure and blast induced acceleration at the head (or ear) and chest with estimates of injury threshold.

The benefits in personal safety gained by using a protective ensemble that is particularly designed for the application are evident. The stable helmet systems (HDH, Sport), which permit the integration of a full-face (5.7mm) visor, were most effective in reducing the overpressure experienced at the ear to levels where there was less than a 50 percent probability of an ear drum perforation for the entire range of blast conditions tested. These same helmets were similarly the most successful in reducing the blast induced head acceleration injury experienced at survivable levels, even at the largest simulated AP mine blasts (200g C4). The HDH helmets, based on a PASGT-style helmet with a full-face visor and a much improved retention system, proved to be the best performers overall against all mine blasts. Hardhat helmets with a full-face visor were moderately effective in providing blast protection against the smallest mines (50g C4), as was the case of a PASGT-style helmet with goggles and minimal facial protection. An increase in explosive content of the mine (100 and 200g C4) clearly escalated the injury severity that would be experienced by the wearer of a Hardhat; a very high likelihood of permanent hearing loss and a potentially unsurvivable head concussion could be anticipated. The open-faced PASGT-style helmet with goggles performed poorly against the larger mines compared to the helmets featuring a full-faced visor on a stable platform. In fact, the anticipated level of protection offered by the helmet without a visor against blast overpressure and head acceleration is comparable to not wearing any head protection and may sometimes actually escalate the injury potential. This result can be attributed to the poor suitability of the design for the particular demining application and related blast threats.

The HDE demining ensembles (Basic and Enhanced) offered significant reductions in transmitted overpressure to the chest wall and in gross chest accelerations compared to the case of a flakvest or an unprotected mannequin. At the largest blast AP mine threat of 200g C4, it was apparent that the hybrid construction of the HDE's, involving soft and rigid ballistic materials with an energy absorbing layer, proved to be more suitable for the demining application compared to a flakvest. The flakvest offered a level of fragmentation resistance but did not contribute toward reducing blast induced chest acceleration and transmitted overpressure. The construction of a flakvest, comprised entirely of soft ballistic layers, was illustrated to actually amplify the loading that would be experienced by an unprotected mannequin.

This study was the first systematic attempt to elucidate the blast performance of personal protective ensembles for the specific purposes of demining. Equipment used must be considered in the context of the blast and fragmentation threats posed by the full range of blast AP mine threats. Protection provided against small mines or for one particular position/distance of the deminer may be vastly compromised if the explosive content of the mine increases or the deminer comes into closer proximity to the mine. Studies are currently underway to quantify the effects of distance and position of the deminer relative to the AP mine.

Appendix A

1 Nerenberg, J., Islam, S., Makris, A., Dionne, JP., Chichester, C. "Comparative Study of Different Lightweight Head Protection Systems with Full-Face Visors for Humanitarian Deminers." *Journal of Mine Action*, James Madison University, Harrisonburg, Va., Version 4.2, June 2000.

2 Nerenberg, J., Makris, A. "HDE: Report on Full Scale Testing," Internal Report, Med-Eng Systems Inc., Ottawa, Ontario, Jan. 2000.

3 Adapted from Makris, A., Kleine, H., Fournier, E., Tylko, S. "Blast Induced Head Acceleration Measurements & the Potential for Injury," 15th Int. Symp. *On Military Aspects of Blast and Shock (MABS),* Banff, Alberta, Sept. 14-19, 1997.

4 Fournier, E., Marchand, P. "RCMP Overpressure Test Series," Report by Biokinetics and Associates, Report No. R95-01, Ottawa, Canada, April 1995.

5 Nerenberg, J., Makris, A., Kleine, H., Chichester, C. " The Effectiveness of Different Personal Protective Ensembles in preventing Injury to the Thorax from Blast-Type Anti-Personnel Mines." *Journal of Mine Action*, James Madison University, Harrisonburg, Va., Version 4.2, June 2000.

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