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Comparative Study

of Different Lightweight Head Protection Systems with Full-Face Visors for Humanitarian Deminers

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Introduction

A key component of any Personal Protective Ensemble (PPE) for demining is the helmet and/or face shield. For obvious reasons, protecting the face of a deminer is of utmost importance in case of an accidental detonation of a mine. Currently, a wide range of head and face protective devices are available for the deminer, and this study attempts to evaluate these devices from several perspectives.

Like any other explosive, when an AP landmine detonates, a blast wave is generated along with an impulsive burst of fragments and an intense fire flash spreading in all directions. The impact and ensuing interaction of the blast wave from such a detonation with a victim (a deminer) can lead to a wide range of effects. Under extreme conditions, intense blast loading can lead to shearing of body parts. These injuries occur in the form of traumatic amputations, such as those observed in victims who have stepped on landmines. With respect to the effects that are important for the deminer's head, the extreme levels of blast strength are usually not considered, as the head is usually at least 0.5m away from the mine.

Yet, at these distances, several different effects can occur due to the detonation of a blast type AP mine. The overpressure of the blast wave emanating from the mine can cause injury to the deminer's ears. While ear damage can lead to loss of hearing, this injury is not life threatening, but it is one with potentially detrimental social consequences. When the blast wave interacts with the head of the deminer, violent levels of acceleration can be induced in the victim's head. Due to this acceleration, a range of minor to deadly concussive injuries can occur.

Test set-up of mannequin Figure 1

Photo c/o Med-Eng Systems Inc.

Fragmentation is a potentially lethal threat, even when coming from a blast-type AP mine. Fragments, traveling at extreme velocities, can be composed of gravel, pebbles, sand, mine casing pieces or parts of the mine mechanism. Injuries to the head from fragments include cuts in soft tissues as well as injuries to the brain, brain stem, face and eyes. The eyes are particularly vulnerable to fragmentation injury with blindness being the obvious consequence.

Heat from a blast also can potentially cause injury. If the victim is sufficiently close to the mine, such that parts of the person's body—including the face—become engulfed in the fireball of the explosion, burns can occur.

In order to examine these effects and to evaluate the ability different technology in head protection has in preventing or reducing these effects, simulated blast-type AP mines were detonated in front of instrumented anthropomorphic mannequins realistically placed in the deminer's prodding position.

Experimental Details

Positioning of Mannequins and Instrumentation

Full-scale tests involving instrumented anthropomorphic Hybrid II mannequins (representing the 50th percentile North American male [height: 1.75 m, weight: 77 kg]) were carried out where the mannequins were placed in deminers' positions. In order to place the mannequins in the correct position, an advanced blast resistant positioning apparatus was utilized (Figure 1). For the purposes of this study, two mannequins were used, one on either side of the simulated mine. One mannequin, in a kneeling on one knee position with its sternum 0.66m to 0.68m from the simulated mine (corresponding to 0.80m distance between the mine and the mannequin's nose) represented the typical distance a deminer's sternum would be from a mine while using a prodder of about 40cm (±10cm). In order to examine the effect of distance, the other mannequin was positioned such that its head was 0.70m from the mine. Figure 1 illustrates this test setup, with mannequin one (on the left) being 0.80m from the mine (at the nose) while mannequin two is at 0.70m distance.

Simulated mines, consisting of C4 plastic explosive packed snugly into injection molded puck-shaped plastic containers, were buried with one cm of overburden in front of the mannequins. Three sizes of simulated mines, containing 50, 100 and 200g of C4, were chosen to represent a wide range of blast type AP landmines.

The Sport Helmet Figure 2a

Photo c/o Med-Eng Systems Inc.

In order to quantify the performance of the helmets and visors, each mannequin was instrumented with a cluster of tri-axial accelerometers (PCB) in the head along with a pressure transducer (PCB) for measuring overpressure at the ear. All instrumentation lines were connected via appropriate power supplies and signal conditioning equipment to a computerized data acquisition system. For further detail concerning this experimental procedure, please refer to [Appendix A, 1]. This method of testing is currently under consideration for use by the Canadian Center for Mine Action Technology (CCMAT).

Helmets and Visors Tested

There are several different types of lightweight head and face protection systems available to the deminer, designed and manufactured by several organizations. In this study, three types of lightweight protective helmets were evaluated. The first was the Sport-1 Helmet developed by Med-Eng Systems, which is composed of a lightweight sporting helmet (used for such activities as climbing or kayaking) with a full-face visor mounted onto it (Figure 2a). The sporting type helmet was chosen by Med-Eng because it is lightweight and fits the head snugly, providing enhanced stability and comfort over other common types of helmets. The Sport-1 Helmet visor is mounted by means of aluminum blocks, which are bolted to the helmet and the visor. Standard locking pins allow the visor to be held securely over the face or above the forehead. The visor extends from beneath the chin to the top of the forehead, thereby covering the entire face. The helmet uses a customized three-point retention system, which secures the helmet snugly to the head through the use of a chin-cup.

The Sport-1 Helmets, as constructed by Med-Eng, are normally made with visors of a standard thickness of 5.7mm. In order to observe the effect of thickness on the blast integrity, fragment resistance and other performance measures for this study, the Sport-1 Helmets were made with visors of two other

Construction Hard Hat Figure 2b

Photo c/o Med-Eng Systems Inc.

nominal thickness values, 4.5mm and 5mm.

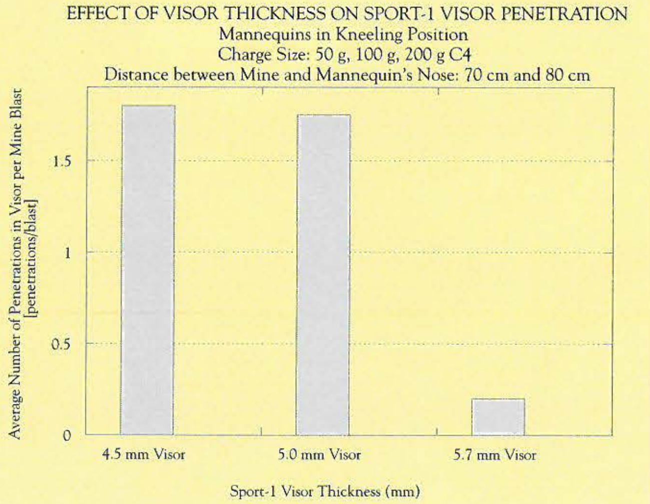
The second type of helmet tested was a construction hardhat mounted with a full-face visor (Figure 2b). This system, designed and constructed by another organization, has a 4.3mm thick ballistic visor mounted by means of plastic mounting blocks on both sides of a construction hardhat. The visor covers the area from beneath the chin to the top of the forehead. Retention to the user's head is achieved by the use of an under-the-chin strap. The visor is mounted on the back of the helmet such that the brim of the helmet does not interfere with the visor (the helmet is worn backwards so that the visor covers the face). The visor cannot be locked in the open or closed positions, rather it is held by friction. This Hardhat head protection system has not been developed by MES, differing significantly in design from the Hardhat helmets (Hardhat-1 and Hardhat-2) evaluated in [Appendix A, 1].

The third type of system tested, also built by another institution, is a full-face visor mounted on an adjustable Headband (Figure 2c). No chinstrap is provided on this Headband system, but it is expected to remain snug on the head by adjusting its circumference. The visor is of sufficient size to provide continuous protection from the neck up to and including the forehead. Similar to the Hardhat system, this visor cannot be locked open or closed, but it is held by friction. The nominal thickness of the visor is 4.8mm.

Use of a Chest Plate

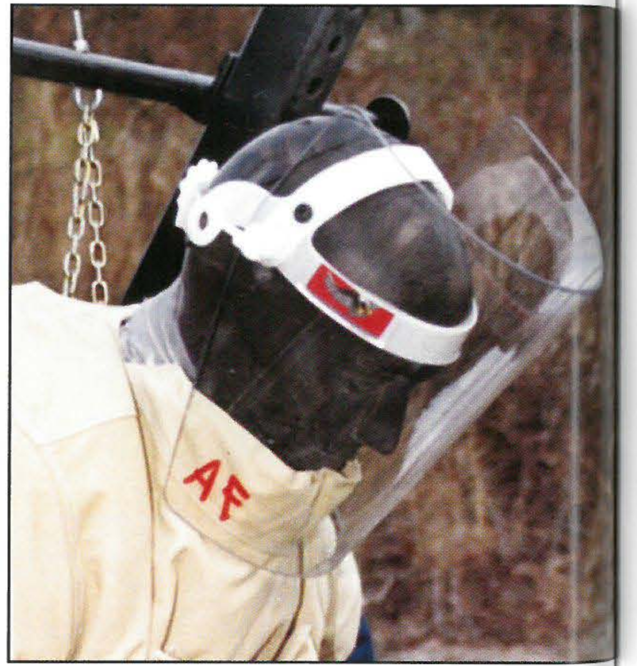
The HDE Demining Ensemble, developed by Med-Eng Systems to provide protection to the deminer's body, uses a chest plate designed to integrate with the visor of a demining helmet. The bottom of the visor tucks in behind the chest plate, thus providing continuous protection from the chest to the top of the head (Figure 2a). The role of the overlapping chest plate and visor is to prevent the mine blast from reaching inside the visor and to aid in keeping the visor over the deminer's face during such a blast. During most tests with the Med-Eng Sport-1 helmets, the full HDE Demining Ensemble with its chest plate, recommended by Med-Eng Systems, covered the body of the mannequins. In some tests, in order to evaluate its effect, the chest plate of the HDE was removed.

Average number of complete penetrations through visors mounted on Sport-1 Helmet' effects of visor thickness Figure 3a



Full-face visor mounted on adjustable headband Figure 2c

Photo c/o Med-Eng Systems Inc.



The Hardhat and the Headband systems, on the other hand, are not designed to be used with an integrated chest plate and are most often used with some sort of soft ballistic apron or vest. Due to this use, there is a clear and open path for the blast to reach inside of the visor and the user's face. Furthermore, due to the shape of these visors, they would not be able to integrate properly with the HDE chest plate. With these factors at hand, in the tests described herein, these two systems were used in conjunction with the HDE Demining Ensemble, but the chest plate was removed in order to simulate a standard flakvest or ballistic apron.

Results and Discussion

Visor Penetration

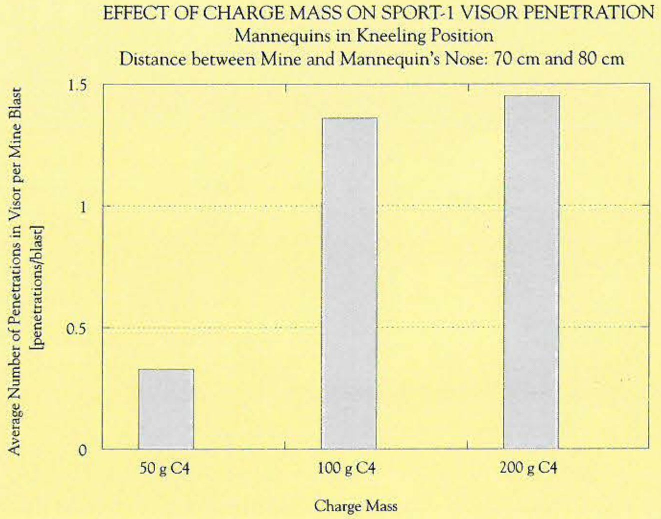
One of the main objectives of a visor is to protect the face from fragments emanating from the detonation of the mine. Whether a visor will be penetrated is dependent on several factors, such as visor thickness, mass of the explosive charge, distance between the mine and the visor, depth of burial and the size and density of fragments in the soil.

From this study, it has been ascertained that even a slight increase in visor thickness can have a dramatic effect on the levels of fragmentation protection to the face and head. Figure 3a illustrates the effect of the different visor thickness mounted on the Sport-1 helmets; the thinner gauge visors performed poorly when compared to the thickest visors. On average—over all charge sizes and distances from the charge—the 4.4mm and 5mm visors were penetrated 1.8 and 1.75 times per blast, respectively, while the 5.7mm visor was penetrated only 0.20 times per blast. These results indicate that for the thinner visors between one and two fragment penetrations were likely to occur in each test, but for the thicker visors, a penetration would occur on average only every fifth test. These results are averaged over all three sizes of simulated mines used at both standoff distances.

The effect of charge mass on visor penetration is illustrated in Figure 3b, which shows that the number of penetration through the Sport-1 Helmet visors (all thicknesses) per blast increases with charge mass from 0.3 per test for 50g C4 to 1.4 for 200g C4.

When a mine detonates, the fragment density (the number of fragments in a given area) decreases dramatically with distance from the mine. Therefore, as a deminer increases his distance from a mine, or any other detonation, one can expect to interact with, on average, fewer fragmentation particles emanate. Furthermore, as the distance increases, the energy of the fragmentation particles decreases. Due to these factors, one would expect fewer fragmentation penetrations as the distance increases from the mine. This supposition is confirmed in Figure 3c where the number of penetrations per test at a distance of 0.8m, on average, was approximately half of that when the visors were 0.7m from the mine.

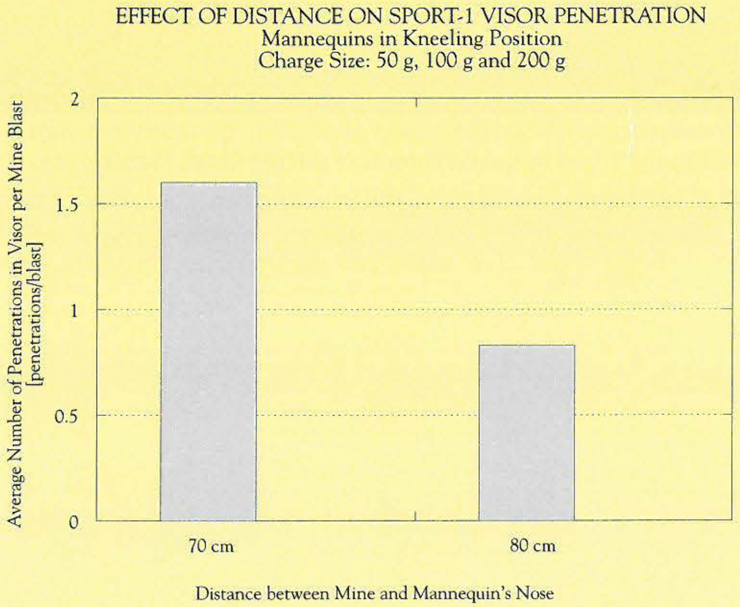
Average number of complete penetrations through visors mounted on Sport-1 Helmets' effects of charge mass Figure 3b



Visor Shattering and Cracking

The penetration resistance of the Hardhat and Headband systems has not been directly compared to the performance of the Sport-1 helmets because a different phenomenon occurred with these systems. Instead of a fragment punching a hole in the visor, in many tests, these visors broke into two or more pieces. In comparison, the 4.4mm visor of the Sport-1 helmet was cracked on two occasions, but this crack was far less catastrophic in nature. Rather than the visor breaking into pieces, a 5-7cm long cut was made, but the overall integrity of the visor remained. This result illustrated that the visors of the Headband and Hardhat systems are far more brittle and prone to

Average number of complete penetrations through visors mounted on Sport-1 Helmets' effects of distance Figure 3c



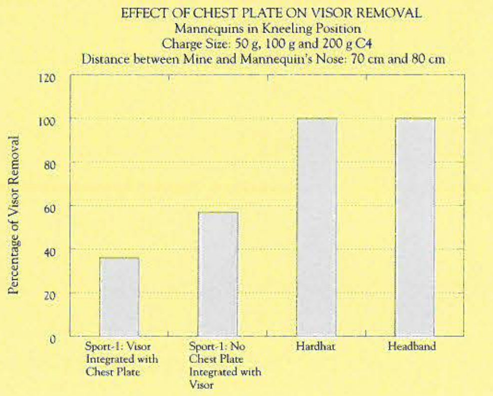
Visor from Hard Hat ejected from face and found in front of mannequin after blast Figure 5a

Photo c/o Med-Eng Systems Inc.

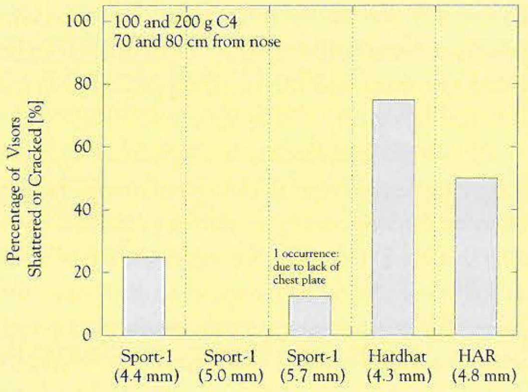
Visor from Headband system ejected from face Figure 5b

Photo c/o Med-Eng Systems Inc.

Percentage of visors removed from face during blast, illustrating effect of overlapping chest plate and properly mounted visor Figure 6



Percentage of visors shattering or cracking for the various head protection systems tested when facing 100g and 200g simulated mines Figure 4



failure than the visors manufactured by Med-Eng Systems. Figure 4 shows the percentage of helmet visors which cracked or shattered for all five helmet types when facing the 100 and 200g C4 mines (the 50g C4 mine results are not included, as this threat level never caused any visors to shatter). It can be seen that the Hardhat visor, which was the thinnest of all those tested, cracked and shattered most readily followed by the Headband system.

Effect of Chest Plate on Visor Removal

In order to provide effective and continuous protection to the face of a deminer during an accidental detonation, the combination of a full-face visor mounted on a stable helmet platform and integrated with an overlapping chest plate is imperative. A visor that is not securely mounted has a high probability of being removed during the blast event, creating the possibility of secondary fragmentation, overpressure and heat reaching the exposed face. Figures 5a and 5b illustrate examples in which the visors of the Headband and Hardhat systems were ejected from the mannequin's face during the blast event. Figure 6 illustrates that when a visor is not properly held in place on a stable helmet platform combined with an overlapping chest plate, it is much more likely to be removed from the face during the blast. The Hardhat and Headband systems had their visors removed from the face in 100 percent of the 18 tests, independent of charge size and distance from the mine. However, when the Sport-1 helmet was used with an integrated chest plate, the visor was removed in just over 25 percent of the 19 tests (usually when a larger charge size was used or when the visor was at the closer distance to the charge). The benefit of a stable helmet platform alone was illustrated when the interfacing chest plate was removed from the HDE, as the visor was removed in 60 percent of the 14 experiments. That is, more often than when the Sport-1 helmet was used with a chest plate but much less than when an unstable mounting platform was used without an integrated chest plate. It should be noted that the Sport-1 helmet, as part of this study, was in its prototypical stage. Due to the occasional failure when the visor was removed during the mine blast, the Sport-1 helmet is being extensively revamped and improved in order to prevent similar occurrences in future tests.

Consideration of Heat Effects

Figure 7 provides evidence that protection from the thermal effects of a detonating mine is required. In both pictures, the detonation of the mine created a fireball that easily reached the heads and torsos of the mannequins. In order to protect the deminer from receiving burns as a result of this fireball, protective clothing is required. The ability of a visor to remain in place during the blast event will prevent burns.

Effects of Helmets and Visors on Ear Overpressure

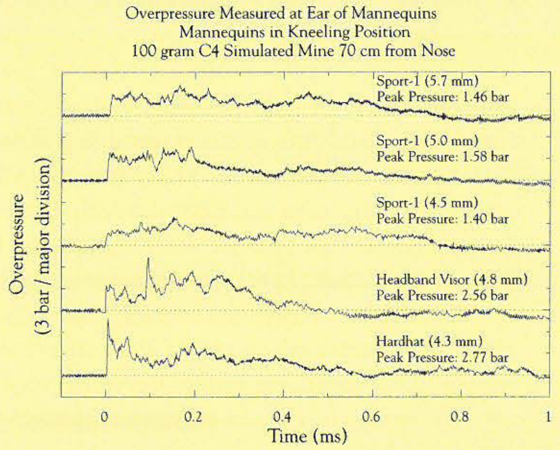
As part of this study, pressure measurements were made at the ear of the mannequin in order to evaluate the effectiveness of the different head protection systems in reducing the overpressure levels that reach the ear of a deminer in the case of an accidental detonation. Figure 8a shows typical traces of overpressure measurements obtained at the mannequins' ears when they faced a blast from the 100g C4 simulated mine at a distance of 0.70m. Figure 8b illustrates traces when facing the 200g C4 simulated mine at a distance of 0.80m. From both figures, it can be observed that the peak overpressure for the Sport-1 helmets is essentially independent of visor thickness but that the peak pressure increases significantly for both the Headband and Hardhat systems. This result is not surprising, as one would expect the peak pressure reaching the ear to be a function of geometry. The Sport-1 helmets have the advantage because their visors are tucked in behind a chest plate to limit the blast overpressure's ability to reach the ear. The Hardhat and Headband systems do not operate in this fashion, so the blast wave can easily get behind the visor and readily reach the ear, which most likely contributes to the higher overpressure (this factor also causes the visor and headgear to be easily removed from the head during the blast event).

Figure 9 shows average peak overpressures mea-

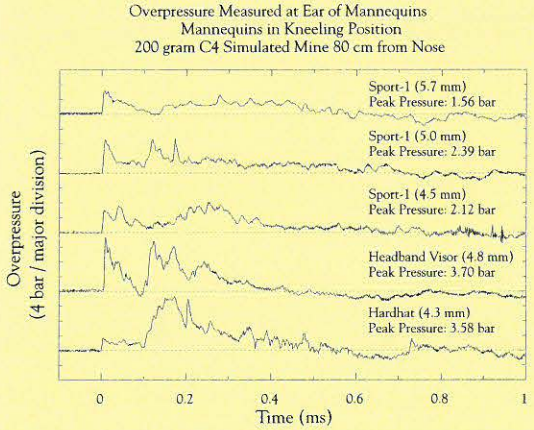
Fireball from detonation of simulated mine enveloping the heads of the mannequins Figure 7

Photo c/o Med-EngSystems Inc.

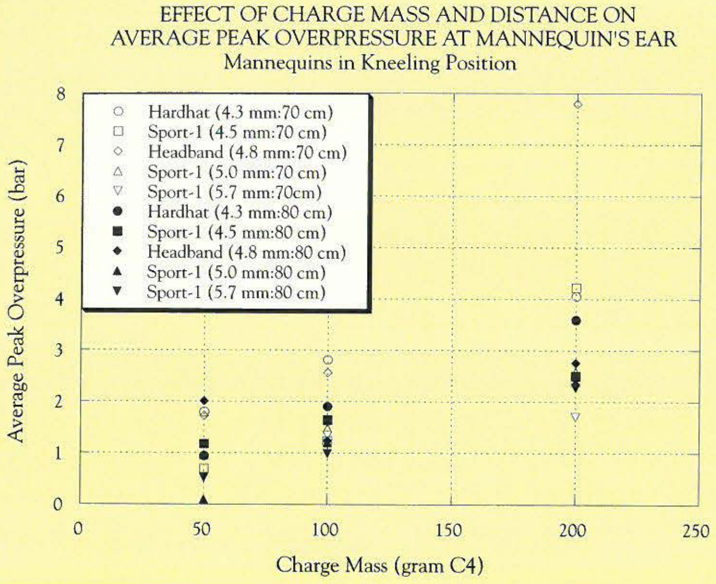
Typical overpressure signals recorded at the mannequin's ear for different head and face protection systems, charge masses and distances between the mine and the mannequin's nose. 100g C4 at a distance of 70cm Figure 8a



Typical overpressure signals recorded at the mannequin's ear for different head and face protection systems, charge masses and distances between the mine and the mannequin's nose. 200g C4 at a distance of 80cm. In both cases, the mines had an overburden of one cm. Figure 8b

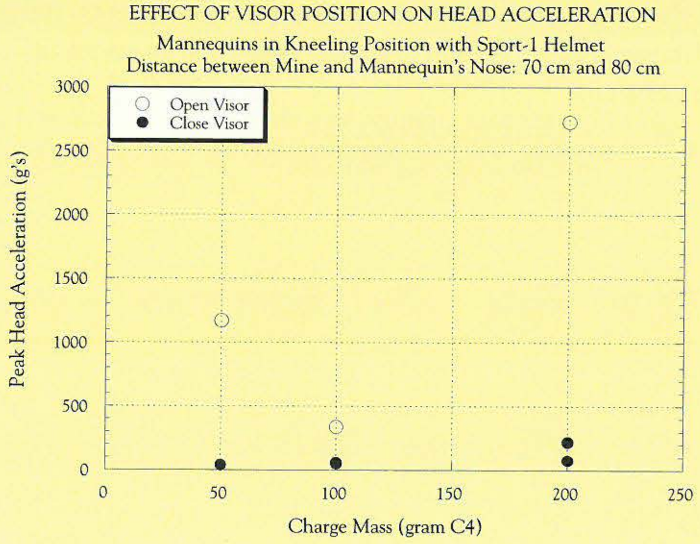


Average peak overpressure measured at the mannequin's ear for different head and face protection systems with mines at distances of 70cm and 80cm from the mannequin's nose Figure 9



sured at the ear of the mannequins for different charge masses and both distances tested. It is shown that the peak overpressure at the ear increases with increasing charge mass and decreases with distance for a particular type of head protection system. In general, the measured peak ear overpressures for all Sport-1 helmets are less than those for Hardhat and Headband systems, which can be attributed to the reasons stated above. For further discussion on the ear overpressure in a demining context, please see [Appendix A, 1].

Effect of visor position (open or closed) on head acceleration Figure 10



Effects of Visor Position on Head Acceleration

A visor is an essential part of the overall head and face protection system and should be kept in a closed position during demining. In many demining theaters, deminers tend to keep their visors open to gain comfort in a hot climate or due to limited visibility because of scratching and fog. This practice may have severe consequences in the event of a detonation. There is the obvious effect of leaving the face exposed to the blast wave and fragmentation, thereby dramatically increasing the chance for severe injury to the face, such as blindness. However, the other effects not often thought of are the accelerative or concussive effects on the head. With the visor open, a large concave surface area is created for the helmet and visor to catch and trap the blast wave. This effect can cause the head to be accelerated backwards at a rate much higher than when the visor is in the closed position (the blast can pass over the relatively streamlined, convex surface of the visor in its closed position). Figure 10 shows the effect of open and closed visors on the head acceleration for the Sport-1 helmet and for different charge masses. The effect of a visor position is obvious, as the peak acceleration can be an order of higher magnitude with an open visor compared with a visor in the closed position.

Conclusion

An initial evaluation of a range of lightweight demining helmets has been performed from several perspectives. It has been shown through tests designed to accurately represent an actual demining accident scenario that, with respect to lightweight helmets, several factors must be considered in order to provide the deminer with adequate protection.

By performing tests with visors that range in thickness, it has been demonstrated that even a small increase in visor thickness can tremendously affect the ability of a visor to prevent high velocity fragmentation from reaching the face of a deminer. In the tests performed for this study, it was demonstrated that by increasing visor thickness from five to 5.7mm, one could decrease the chance of a fragment penetration by over eight times. Furthermore, the effect of decreasing one's distance from a mine was shown to a have a marked effect on whether a fragment would penetrate a protective visor—thus indicating the importance of increasing stand-off distance whenever possible.

Visor manufacturing processes were also illustrated to be of paramount importance. The visors not manufactured by MES were more likely to catastrophically crack or shatter into several pieces, whereas the visors on the Sport-1 helmets did not show this tendency. In fact, it was demonstrated that visor thickness is not indicative of potential for failure compared to how well the visor was manufactured.

In order to ensure that the deminer is protected from a detonating mine, it is required that a protective system remain over the head and face throughout the blast event. It has been demonstrated that in order to ensure this scenario, both a stable helmet platform and an integrated chest plate are essential. The Hardhat and Headband systems, which have neither feature, had their visors removed from the faces of the mannequins in every test—even against the smallest of the charge sizes. On the other hand, the form-fitting Sport-1 helmet (unlike the Hardhat, which, like any other construction hardhat, sits high on the head) and visor that can be integrated with a chest plate were removed in far fewer tests and, usually, only when facing a large charge size.

One rarely considered benefit of having a visor remain in place over the face throughout a mine detonation was demonstrated by observing the intense short-lived fireball, which can easily engulf the deminer's upper body, including the face. The presence of a visor will ensure that burn injuries are kept to a minimum. The overpressure at the ear was also shown to be positively affected by a proper head protection system, as the Sport-1 helmets consistently permitted lower peak overpressure levels to reach the ear, as compared to the Hardhat and Headband systems.

All of this evidence provides a clear picture of the equipment required by deminers to effectively perform their duties. If one chooses a lightweight head/face protective system, it should have several key characteristics. It should have a visor that is manufactured properly in order to prevent catastrophic failure, and one of sufficient gauge to minimize the possibility for fragmentation penetration. It should be mounted onto a stable platform—most likely a snug fitting and strong helmet with a comfortable and effective retention system. How the helmet interacts with the other protective equipment should also be taken into account. The bottom of the visor should integrate with an overlapping chest plate, as this structure greatly enhances the ability of the helmet to function properly. Finally, the helmet's use and care is of great importance. If the visor is treated properly in order to prevent scratches and maintain clarity, it is more likely to be used in the down, or closed, position. A visor used in the open position not only opens the face to the threat of fragmentation and heat but it also increases the possibility of concussive injury in the event of a detonation. ■

Appendix A

[1] Makris A. Nerenberg J, "Full Scale Evaluation of Lightweight Personal Protective Ensembles for Demining in Providing Protection Against Blast-Type Anti-Personnel Mines," In *Journal of Mine Action*, James Madison University, Harrisonburg, Va., Version 4.2–Online, June 2000.

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