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

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1. Introduction

A key component for of any personal protective ensemble for demining is the helmet and/or face shield. For obvious reasons, protecting the face of a deminer is of utmost importance in the case of an accidental detonation of a mine. Currently, there is a wide range of different head and face protective devices available for the deminer, and this study attempts to perform a first evaluation of these devices from several different perspectives.

Like any other explosive, when an anti-personnel (AP) landmine detonates, a blast wave is generated, along with an impulsive burst of fragments and an intense fire flash, propagating away in all directions. The impact and ensuing interaction of the blast wave from such a detonation with a victim, e.g., a deminer, can lead to a wide range of effects. Under extreme conditions, intense blast loading can lead to shearing of body parts, 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 head of a deminer, the extreme levels of blast strength are usually not considered as the head usually at least 0.5 m away from the mine.

However, 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 ears of the deminer. While ear damage can lead to loss of hearing, this is not a life threatening injury, but is an injury 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 head of the victim. Due to this acceleration, a range of concussive injuries can occur, from minor to unsurvivable.

Fragmentation is a potentially lethal threat, even when coming from a blast-type anti-personnel 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.

The final effect of a blast with potential to cause injury is that from heat. 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 of different concepts in head protection to prevent injury, or reduce these effects, simulated blast-type anti-personnel mines were detonated in front of instrumented anthropomorphic mannequins, realistically placed in positions representative of a deminer prodding for a mine.

2. Experimental Details

2.1 Positioning of Mannequins and Instrumentation

Full scale tests involved instrumented anthropomorphic Hybrid II mannequins, representing the 50th percentile North American male (height: 1.75 m, mass: 77 kg), placed accurately in positions representative of those used by deminers. In order to reproducibly and consistently place the mannequins in position, an advanced blast resistant positioning apparatus was utilized (see Fig.1). For the purposes of this study, two mannequins were used, one on either side of the simulated mine. One mannequin was placed in a kneeling-on-one-knee position with its sternum 0.66 m to 0.68 m from the simulated mine (corresponding to 0.80 m distance between the mine and the mannequin's nose), which represented the typical distance a deminer's sternum would be from a mine while prodding with a prodder of approximate length 40 cm (±10 cm). The other mannequin was positioned such that its head was 0.70 m from the mine, in order to examine the effect of distance. Figure 1 illustrates this test setup, with mannequin 1 (on the left) being 0.80 m from the mine (at the nose) while mannequin 2 is at 0.70 m distance.

Figure 1. Test set-up showing mannequins in kneeling-on-one knee position wearing Sport helmets and a Demining Ensemble, held in position by test apparatus. Mannequin 1 (on left) is positioned with nose 0.80 m from mine, while mannequin 2 is positioned with nose 0.70 m from mine.

Simulated mines, consisting of C4 plastic explosive packed snugly into injection molded puck-shaped plastic containers, were buried with 1 cm of overburden in front of the mannequins. Three sizes of simulated mines were used containing 50, 100 and 200 gram of C4, chosen to represent a wide range of blast type anti-personnel landmines.

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 [1].

2.2 Helmets and Visors Tested

As stated, there are several different types of lightweight head and face protection systems available to the deminer, designed and manufactured by several different organizations. In this study, three types of lightweight protective helmets were evaluated. The first was the *Sport Helmet* developed by Med-Eng Systems, which is composed of a lightweight sporting helmet (used for such activities as climbing or kayaking) onto which is mounted a full face visor (see Fig. 2a). The sporting type helmet was chosen because of its lightweight and snug fit to the head, which provide enhanced stability and comfort over other common types of helmets. The Sport helmet has its visor 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 full front of the 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.

(a) (b) (c)

Figure 2. Head and face protection systems tested. (a) Sport helmet with a full-face visor, (b) Hardhat helmet with a full-face visor, and (c) Headband with a full-face visor.

The Sport Helmets, as constructed by Med-Eng, are normally made with visors of a standard thickness of 5.7 mm (0.224"). In order to observe the effect of thickness on the blast integrity, fragment resistance and other performance measures, for this study, the Sport Helmets were made with visors of two other thicknesses of nominal values of 4.5 mm (0.173"), and 5.0 mm (0.196").

The second type of helmet tested was a construction hardhat mounted with a full face visor (see Fig. 2b). This system, designed and constructed by Hameed and Ali Research Center (HARC) Pakistan, has a 4.3 mm (0.17") 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 (therefore, the helmet is worn backwards in order that the visor covers the face!). The visor cannot be locked in the open or closed positions, but is held in place by friction. It should be noted that this *Hardhat* head protection system differs significantly in design from the Hardhat helmets (*Hardhat-1* and *Hardhat-2*) evaluated in [1].

The third type of system tested, manufactured by Lightweight Body Armor Limited (LBA) United Kingdom, is a full-face visor mounted on an adjustable *Headband* (see Fig. 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 as 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 is held by friction. The nominal thickness of the visor is 4.8 mm (0.19").

2.3 Use of a Chest Plate

The Demining Ensemble, developed by Med-Eng Systems to provide protection to the body of a deminer, 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 (as can be seen in Fig. 2a). The role of the overlapping chest plate and visor is to prevent the blast from the mine from reaching the inside of the visor and aids in keeping the visor over the face of the deminer during a blast. During most tests with the Sport helmets, the full Demining Ensemble with its chest plate, recommended by this manufacturer, was used to cover the body of the mannequins. However, in some tests, in order to evaluate its effect, the chest plate of the Demining Ensemble was removed.

The Hardhat and the Headband systems, on the other hand, are not necessarily designed to be used with an integrated chest plate, and are often used with some sort of soft ballistic apron, vest, or nothing at all. Because of this, there is a clear and open path for the blast to reach the inside of the visor, and therefore the face of the user. Furthermore, due to the shape of these visors, they would not integrate properly with the chest plate of the Demining Ensemble. Due to these factors, in the tests described herein, these two systems were used in conjunction with the Demining Ensemble, but with the chest plate removed in order to simulate a standard flakvest or ballistic apron.

3.0 Results and Discussion

3.1 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 size and density of fragments in the soil, among others.

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 thicknesses mounted on the Sport helmets; the thinner gauge visors performed poorly when compared to the thickest of the visors. On average – over all charge sizes and distances from the charge – the 4.4 mm and 5.0 mm visors were penetrated 1.8 and 1.75 times, respectively, per blast, while the 5.7 mm (nominally 1/4") visor was penetrated only 0.20 times per blast. This indicates that for the thinner visors between 1 and 2 fragment penetrations were likely to occur in each test, but for the thicker visor, a penetration would occur on average only every fifth test. These results are averaged over all three sizes of simulated mines used, at both stand-off distances.

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

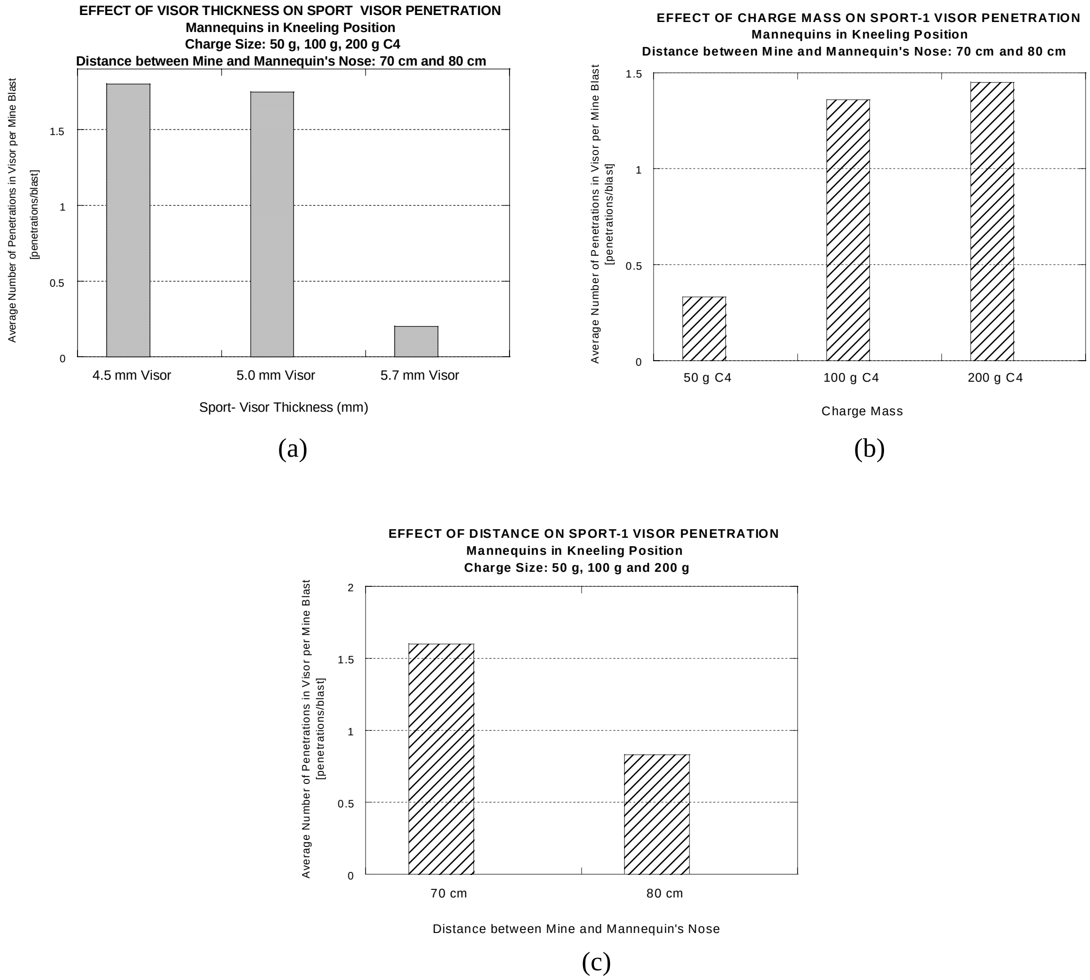


Figure 3. Average number of complete penetrations through visors mounted on Sport helmets. (a) effect of visor thickness, (b) effect of charge mass, and (c) effect of distance.

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

3.2 Visor Shattering and Cracking

The penetration resistance of the Hardhat and Headband systems has not been directly compared to the performance of the Sport helmets, above, because a different phenomenon occurred with these systems. Instead of a hole being punched in the visor by a fragment, in many tests these visors break into two or more pieces. In comparison, the 4.4 mm visor of the Sport helmet was cracked on two occasions, but this crack was far less catastrophic in nature. Rather than the visor breaking into pieces, a 5 to 7 cm long cut was made; but the overall integrity of the visor remained. This illustrated that the visors manufactured by HARC and LBA (the Headband and Hardhat systems) are far more brittle and prone to failure than the visors manufactured by Med-Eng Systems (Sport helmet systems). Figure 4 shows the percentage of helmet visors which cracked or shattered for all five helmet types, when facing the 100 and 200 g C4 mines (the 50 g C4 mine results are not included as this threat level never caused any visors to shatter). It can be seen that the Hardhat visor (HARC), which was the thinnest of all those tested, cracked and shattered most readily, followed by the Headband system (LBA).

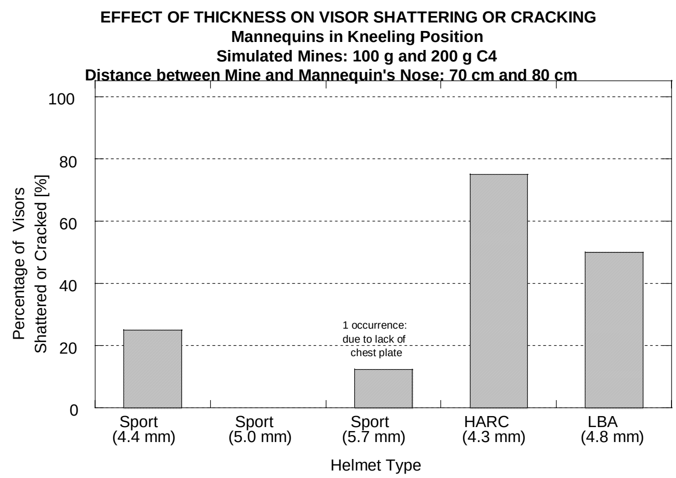


Figure 4. Percentage of visors shattering or cracking for the various head protection systems tested, when facing 100 g and 200 g simulated mines.

3.3 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 use 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 that secondary fragmentation, overpressure and heat can reach the exposed face. Figure 5 illustrates examples in which the visors of the Headband and Hardhat systems were ejected from the face of the mannequin during the blast event. Figure 6 illustrates that when a visor is not properly held in place on a stable helmet platform, integrated 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% of the tests (18 tests), independent of charge size and distance from the mine. However, when the Sport helmet was used with an integrated chest plate, the visor was removed in just over 25% of the tests (out of 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 Demining Ensemble, as the visor was removed in 60% of the experiments (out of 14 tests); i.e., more often than when the Sport 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 helmet, as tested as part of this study, were in their prototypical stage.

(a) (b)

Figure 5. Visor removal during blast. (a) visor from Hardhat ejected from face, and found in front of mannequin after blast, (b) visor from Headband system ejected from face. In both cases visor from Sport helmet remained over face through blast event.

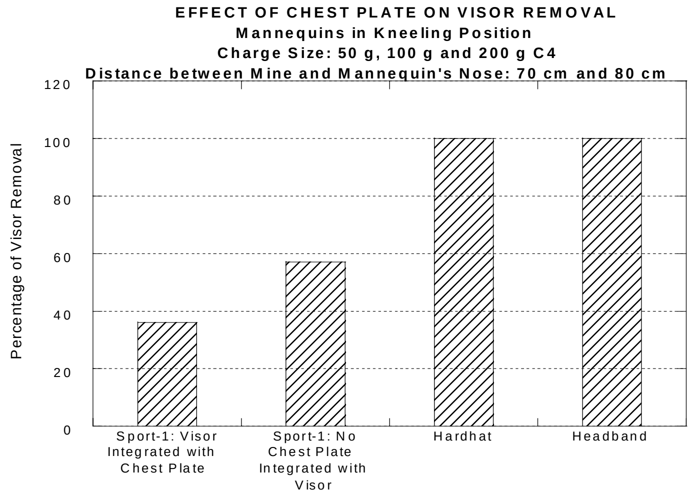


Figure 6. Percentage of visors removed from face during blast, illustrating effect of overlapping chest plate and properly mounted visor.

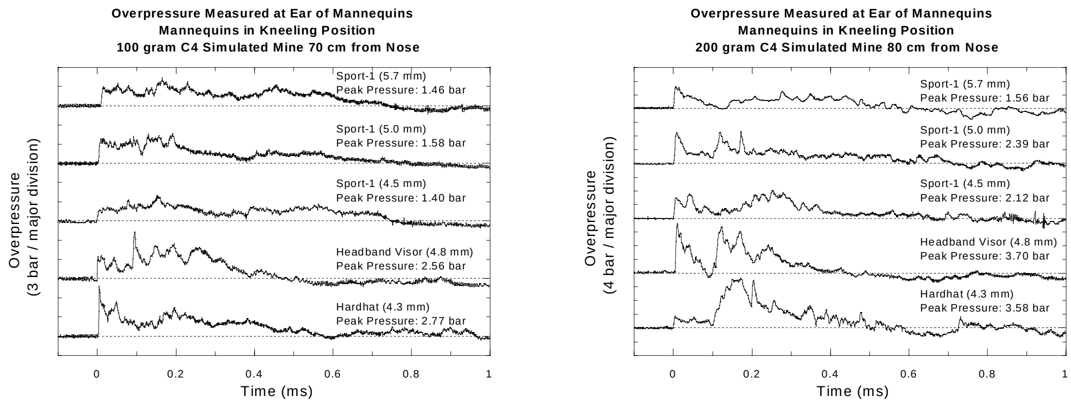
3.4 Consideration of Heat Effects

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 which easily reaches the heads and torsos of the mannequins. In order to protect the deminer from receiving burns due to this, protective clothing is required. The ability of a visor to remain in place over the face of a mannequin during the blast event will serve to prevent burns.

(a) (b)

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

3.5 Effects of Helmets and Visors on Ear Overpressure



(a) (b)

Figure 8. 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: (a) 100 g C4 at a distance of 70 cm and (b) 200 g C4 at a distance of 80 cm. In both cases, the mines had an overburden of 1 cm.

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 ear of the mannequins when the mannequins faced a blast from the 100 gram C4 simulated mine at a distance of 0.70 m. Figure 8b illustrates traces when facing the 200 gram C4 simulated mine at a distance of 0.80 m. From both figures it can be seen that the peak overpressure for the Sport helmets is essentially independent of visor thickness, but that the peak pressure increases significantly for both the Headband and Hardhat systems. This is not surprising, as one would expect the peak pressure reaching the ear to be a function of geometry. The Sport helmets have the advantage of their visors tucked in behind a chest plate, in order to limit the ability of the blast overpressure from reaching the ear. The Hardhat and Headband systems do not operate in this fashion, therefore, the blast wave can easily get in behind the visor and readily reach the ear which most likely contributes to the higher overpressure (as discussed, 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 measured at the ear of the mannequins for different charge masses and both distances tested. It is seen that the peak overpressure at the ear increases with increasing charge mass and decrease with distance for a particular type of head protection system. In general, it was also found that the measured peak ear overpressures for all Sport 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 [1].

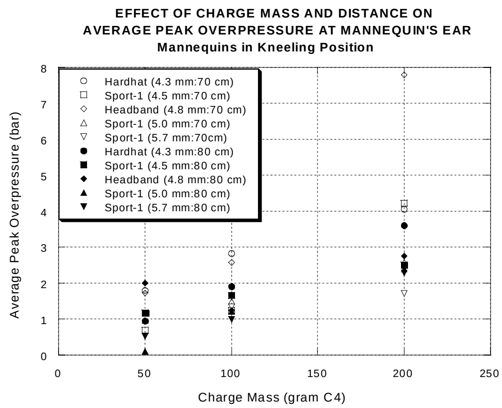


Figure 9. Average peak overpressure measured at the mannequin's ear for different head and face protection systems with mines at distances of 70 cm and 80 cm from the mannequin's nose.

3.6 Effects of Visor Position on Head Acceleration

A visor is an essential part of the overall head and face protection system and should be oriented in a closed position during demining. In many demining theaters, deminers tend to keep their visors open due to poor visibility because of scratching, fogging, or due to seeking of comfort in a hot climate. But 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 increasing dramatically 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, this creates a large concave surface area 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 (when 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 close visors on the head acceleration for the Sport helmet and for different charge masses. The effect of a visor position is obvious as the peak acceleration can be an order of magnitude higher with an open visor compared with a visor in the closed position.

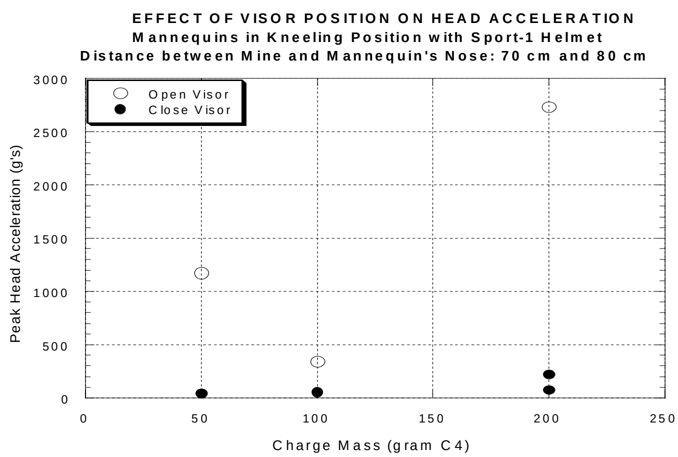


Figure 10. Effect of visor position (open or closed) on head acceleration.

4.0 Conclusions

A first 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 a range of visor thickesses, it has been demonstrated that even a small increase in visor thickness can have a tremendous effect on 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 5.0 to 5.7 mm, one could decrease the chance of a fragment penetration by over 8 times. Furthermore, the effect of decreasing one's distance to 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, as much as possible.

Visor manufacturing processes were also illustrated to be of paramount importance. Some of the visors were shown to be likely to catastrophically crack or shatter into several pieces, whereas the visors on the Sport 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, both a stable helmet platform and an integrated chest plate are required. The Hardhat and Headband systems, which have neither such 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 Sport helmets, with both a form fitting stable helmet (unlike the Hardhat which, like any other construction hardhat, sits very high on the head) and a visor which can be integrated with a chest plate, was removed in far fewer tests, and usually only when facing a large charge size.

One benefit, not often considered, 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 helmets consistently permitted lower peak overpressure levels from reaching 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 is to choose a lightweight head/face protective system, it should have several key characteristics. It should have a visor that is manufactured properly so as to prevent catastrophic failure, and is of sufficient gauge so as 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 retention system which is both comfortable and effective. How the helmet interacts with the other protective equipment used should also be taken into account. The bottom of the visor should integrate with an overlapping chest plate, as this greatly enhances the ability of helmet to function. And finally, in terms of how the helmet is used and cared for is of great importance. If the visor is treated properly in order to prevent scratches and maintain clarity, it is much more likely that the visor will be used in the down, or closed, position. A visor used in the open the position not only opens the face to the threat of fragmentation and heat, but also increases the possibility of concussive injury in the event of a detonation.

References

1. Makris A, Nerenberg J, Chichester C, “Full Scale Evaluation of Lightweight Personal Protective Ensembles for Demining in Providing Protection Against Blast-Type Anti-Personnel Mines”, Presented at: The Fourth International Symposium on Technology and the Mine Problem, March 2000