Testing vs. Reality: A Comparative Analysis of Body Armour Performance Under Lab Conditions

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Abstract. Body armour is critical and essential for the protection of military and law enforcement personnel, yet the gap between laboratory testing and real-world performance remains a significant concern. Standardized testing protocols, such as those measuring resistance to ballistic impact, often fail to capture the complexity of real-world scenarios where body armour is subjected to a wider range of environmental and situational variables. These include factors like user movement, varying impact angles, multi-hit scenarios, and the influence of everyday objects under the body armour vests.

This study explores some of the discrepancies between the controlled conditions of body armour testing in a laboratory environment and its actual use in operational environments. During a series of controlled experiments, coins and mobile phones were placed beneath various types of body armour, including polyethylene and polyaramid-based vests. Ballistic impacts were then applied to measure the extent of backface deformation and to assess whether these objects altered the armour's protective capacity, potentially compromising the safety of the wearer.

The findings of this research reveal significant differences in armour performance when such objects are present, highlighting the possible need for updated testing protocols that consider the real-world conditions in which body armour is used. This study aims to contribute to a more accurate understanding of body armour effectiveness, ensuring that protective equipment can address both ballistic and non-ballistic threats posed by carried objects.

1. INTRODUCTION

Body armour serves as a critical component of personal protection for military and law enforcement personnel, designed to mitigate ballistic threats and reduce fatal injuries in combat and high-risk operations. Modern body armour systems primarily consist of soft armour (made from high-performance fibres such as polyaramid and ultra-high-molecular-weight polyethylene) and hard armour (ceramic, steel or composite plates). Standardized testing procedures, such as those defined by the National Institute of Justice (NIJ) [1] and the STANAG 2920 standard [2], provide a controlled framework for evaluating the ballistic resistance of protective vests. These protocols typically measure factors like penetration resistance and backface deformation (BFD) using specific ammunition types and impact conditions.

While these tests ensure a baseline level of protection, they often do not fully replicate the dynamic conditions experienced in operational environments. Real-world use of body armour introduces numerous variables, including environmental exposure, multi-hit scenarios, user movement, and the presence of everyday objects carried under the vest. These factors may significantly alter the actual performance of armour in ways that are not currently captured by standardized laboratory assessments.

Several studies have highlighted that body armour performance is influenced by factors such as temperature, humidity, and mechanical wear over time [3], [4], [5]. However, a less-explored aspect is the effect of foreign objects carried under the armour.

While specific studies on items like pens or keychains are limited, there is evidence suggesting that carrying rigid objects under body armour can alter its performance. Discussions on backface deformation in body armour suggest that the presence of hard objects can change the way ballistic energy is absorbed and dissipated, potentially increasing the risk of injury. One overlooked factor is the influence of items such as mobile phones and coins positioned benhind the armour. These objects may alter the armour's ability to dissipate energy, potentially increasing backface deformation (BFD) and even leading to localized penetration. This study investigates how such objects affect body armour performance under ballistic impact, with a specific focus on soft polyethylene and polyaramid-based vests. Regarding the influence of clothing and/or objects present under or over the body armour, no scientific literature was retrieved, except for a study regarding the possible increased risk of injury for underwire bras [6]. Only indirect reference to the risk of objects carried under body armour have been found in documents related to how body armour should be used, but without any supporting references backing these claims.

This study aims to assess the risks posed by everyday objects worn beneath body armour, evaluating how common foreign objects, such as coins, mobile phones, and identification tags (also known as 'dog tags'), influence the ballistic performance of soft body armour systems, particularly in terms of backface deformation and potential penetration risks.

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2. EXPERIMENTAL SETUP

The research described here, considers two different ballistic personal armour systems, respectively aramid- and polyethylene- based vests. Three different objects, namely mobile phones, coins and military ID positioned benhind armour were studied (see setup in Figure 1). The selected objects were chosen based on their common presence in the shirt pockets of personnel wearing body armour. These items differ in composition, thickness, and structural integrity, making them intersting candidates for evaluating their effect on armour performance.

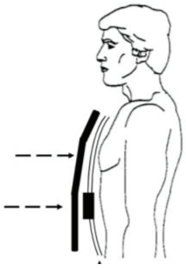

Figure 1. Example of equipment worn under the torso body armour

All the experimental ballistic tests were carried out in the firing range of the Department of Weapon Systems and Ballistics at the Royal Military Academy (Belgium). . A series of tests followed the NIJ0101.04 standard, and in particular the threat level IIIa was considered for this research which among other things evaluates the backface signature of the body armour when impacted by specific handgun rounds (9 mm FMJ RN and .44 Mag JHP). For the witness material, a gelatine block (NATO composition) of 15 x 15 x 45 cm and Roma Plastilina No. 1 modelling clay were used. Table 1 shows the overview of the different ballistic tests that were performed.

Table 1. Ballistic tests performed over the different equipment

	Polyethylene vest	**Aramid vest**
50 cents coin	9 mm FMJ RN	9 mm FMJ RN
	.44 Mag JHP	.44 Mag JHP
Smartphone	9 mm FMJ RN	9 mm FMJ RN
	.44 Mag JHP	.44 Mag JHP
Military ID tag	.44 Mag JHP	----

For the experimental tests, a universal receiver with interchangeable barrel was used and the targets were placed at 15 m from the muzzle. A double velocity base was used to measure the projectile velocity and a high speed camera to capture correctly the movement of the projectile and/or target inside the gelatine block.

3. RESULTS AND DISCUSSION

3.1 50 cents coin test

3.1.1 Roma plastilina No. 1

The experimental tests for the 50 cents euro coins are presented in Figure 2. Figure 3 presents the maximum backface signature (BFS) measured in Roma Plastilina No.1 witness material for two types of body armour—polyethylene and aramid—when impacted by different projectiles (9 mm FMJ and .44 Magnum JHP), with a 50 euro coin placed beneath the vest. Additionally, baseline tests were conducted

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for the polyethylene vest without the coin, providing a direct comparison of how the presence of a rigid object affects armour performance.

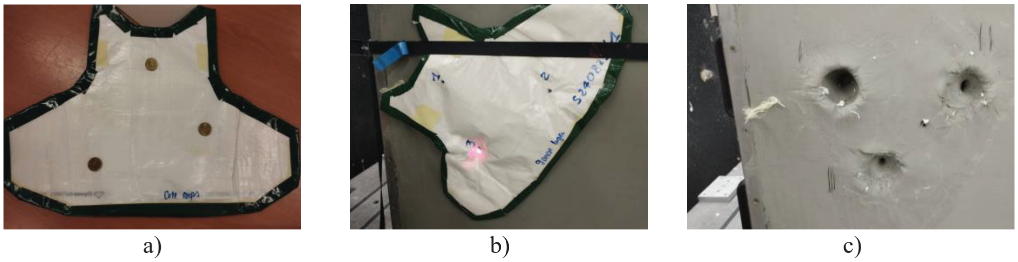


Figure 2. Experimental tests for the 50 cents euro coin: a) body armour vest with the coins (backface shown); b) body armour vest in place against the witness material; c) BFS results after the test

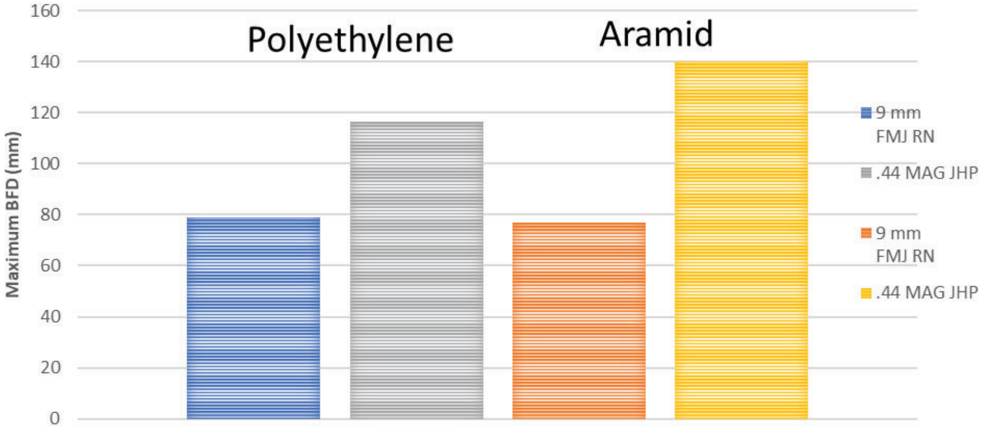


Figure 3. Maximum BFS as a function of the considered threats for two different body armour protection systems for 50 cents coin experimental tests

For polyethylene-based body armour, the baseline BFS values (without a coin) were 25.5 mm and 42.2 mm for 9 mm FMJ and .44 Magnum JHP respectively. Compared to the baseline tests for the 9 mm FMJ and for the .44 Magnum JHP an increase of over 200% and 160% in BFS occurs. These results indicate that the presence of a rigid object (the coin in this case) under the armour possibly significantly amplifies backface deformation, which could lead to a much higher risk of behind armour blunt trauma (BABT) for the wearer, or that the coin is also accelerated at the moment of impact to become a secondary projectile. The coin likely acted as a stress concentrator, altering the way the armour absorbs and disperses the impact energy. Both types of vests materials performed similarly for 9 mm FMJ, with BFS values around 75–80 mm when the coin was present. The aramid vest showed significantly greater BFS (140 mm) for the .44 Magnum JHP, compared to polyethylene (110 mm). This suggests that polyethylene armour distributes the energy more effectively than aramid when a rigid object is present.

The 9 mm FMJ round produced significantly higher BFS values in both vests compared to the baseline, emphasizing that even a low-energy projectile can lead to critical increases in BFS when foreign objects are present. The .44 Magnum JHP caused extreme BFS increases, particularly for the aramid vest, reinforcing concerns about how soft body armour interacts with large-calibre, expanding bullets in real-world conditions, especially during operational use.

In several tests involving the 50 cents coin positioned beneath the body armour, full perforations of the vest were observed when impacted by .44 Magnum JHP projectiles. These perforations occurred in both polyethylene and aramid-based soft armour vests, despite their certification for Level IIIA threats under NIJ 0101.04. The coin itself was not perforated (Figure 4); rather, it acted as a rigid interface that disrupted the normal deformation behaviour of the armour. The projectile, upon impact, was effectively supported by the coin, which appears to have focused and intensified the energy transfer onto a smaller area of the vest, leading to localized failure.

Figure 4. 50 cents euro coin after an impact (full vest perfotation)

3.1.2 Gelatine

In the initial tests, Roma Plastilina No.1 was used as a backing material to measure BFS when a 50 cents coin was placed beneath the polyethylene vest. However, it was observed that the maximum depth of indentation was quite large (see Figure 2c) making it challenging to measure accurately due to the material's non-uniform response and the difficulty in precisely determining the deepest point.

To improve measurement accuracy and obtain a clearer visualization of the deformation, a ballistic gelatine block was used in subsequent tests. Next to this, a skin simulant (based on NATO AEP-94) was added to the gelatine block in order to assess whether additional injury risk would be mostly due to a change in blunt trauma or rather penetrating trauma, while maintaining compliance with recognized ballistic testing methodologies. Figure 5 shows the schematic representation of the experimental tests using the .44 Magnum JHP projectile against the polyethylene vest, with the 50 cents coin, the skin simulant and the gelatine block. Ballistic gelatine is transparent, allowing for direct observation and precise quantification of the amount of deformation.

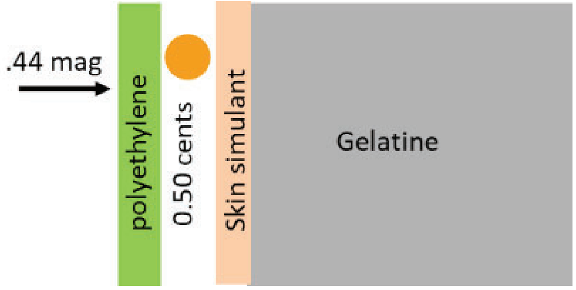
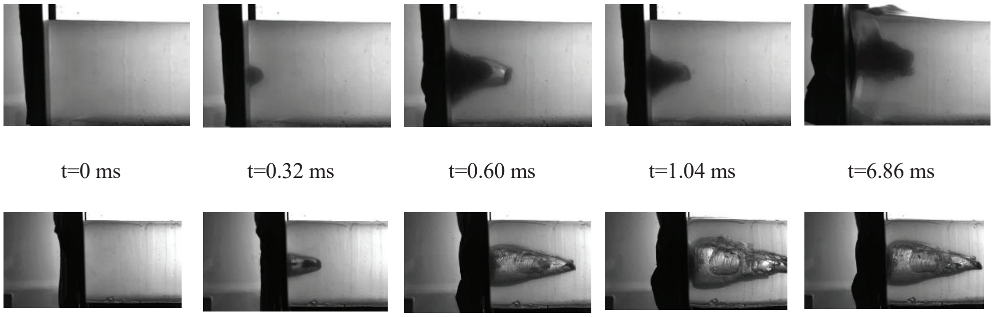


Figure 5. Schematic representation of the experimental tests using the .44 Magnum JHP projectile against the polyethylene vest with, 50 cents coin, the skin simulant and the gelatine block



t=0 ms t=0.32 ms t=0.60 ms t=1.04 ms t=6.86 ms

t=0 t=0.68 ms t=1.23 ms t=3.36 ms t=7.24 ms

Figure 6. High-speed image sequences for the experimental tests of the .44 Magnum JHP projectile against polyethylene vest with 50 cents coin. Top sequence: no perforation of the vest; bottom sequence: full perforation of the vest

Figure 6 shows the experimental results of the .44 Magnum JHP projectile against the polyethylene vest with the 50 cents coin. No perforation of the body armour vest was observed for the top sequence while a full perforation of the vest occurred for the bottom sequence. The test clearly shows that the high levels of BFS as measured during the previous testing are not due to an actual increase in BFS of the armour systems, but rather due to the acceleration of the coin, turning it into a secondary projectile. Although the AEP-94 skin simulant was not intended to be used in this type of testing, the tests indicate that in reality there would also be a high risk of having full skin perforation of the coin and a penetration into the tissue behind it.

Next to these non-perforating tests (i.e. for the vest) multiple instances of full perforation of the body armour vest were also observed. Despite the high-energy impact and the resulting failure of the armour, the coin itself was not penetrated but rather sustained a significant plastic deformation (Figure 7). This suggests that the coin acted as a "rigid" intermediary, concentrating the impact energy and disrupting the vest's ability to absorb and effectively dissipate the projectile's energy. Significant differences were observed in terms of maximum penetration depth. When no perforation of the vest occurred (Figure 6 top), the coin penetrated up to 74 mm into the gelatine block. However, in cases of full perforation of the vest (Figure 6 bottom), the maximum penetration increased substantially, reaching up to 112 mm. These results highlight the critical role of the armour in mitigating projectile energy and demonstrate how the presence of a rigid object like a coin can contribute to deeper wounding potential, even if the object itself is not fully perforated. The use of transparent gelatine allowed for precise depth measurements and offered a more detailed understanding of the internal damage mechanisms associated with such interactions.


a) b)

Figure 7. a) and b) Example of a 50 cents euro coin and .44 Magnum JHP ammunition after an impact (full vest penetration)

3.2 Smartphone test

In this part, a series of experiments investigated how the presence of a smartphone placed underneath two different types of body armour vests — polyethylene and aramid aramid — affects the maximum BFS when impacted by 9 mm FMJ and .44 Magnum JHP ammunition (see Figure 8). The BFS was measured using Roma Plastilina No.1 as a witness material. Figure 9 shows the maximum BFS as a function of the different calibres for two different body armour protections in the smartphone tests. As the screens readily splintered upon impact, this may lead to additional injuries, but this effect was not evaluated during these tests.

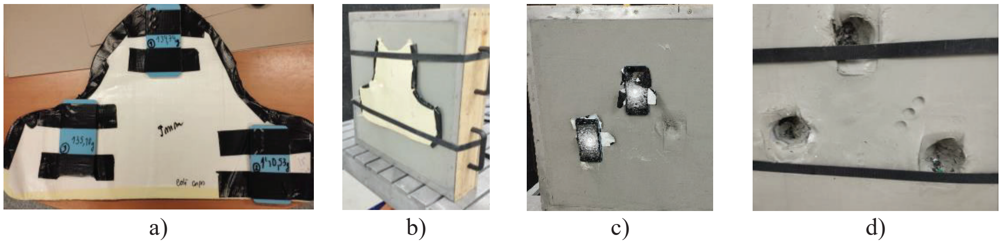

a) b) c) d)

Figure 8. Experimental setup for the smartphones tests: a) body armour vest with the smartphones (backface); b) body armour vest in place against the witness material; c) experimental results after the test with smartphone; d) results after removing the smartphone

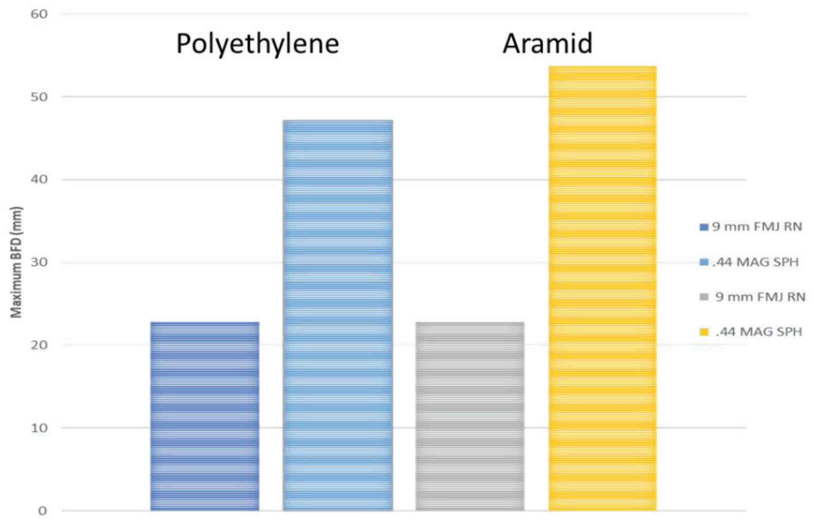


Figure 9. Maximum BFS in function of the different calibres for two different body armour protection in the smartphone experimental tests

The presence of the smartphone did not significantly affect the BFS for both vests under 9mm FMJ (BFS values around 23 mm), likely due to the reduced energy transfer and relatively high stiffness of the phone's internal structure, as the smartphone presents a larger impact area for energy distribution compared to the coin!. The .44 Magnum JHP round resulted in substantially higher BFSs for both armour types, indicating that the higher energy of the .44 Magnum round, combined with the localized resistance and (stiffness of the smartphone, created stress concentration zones, leading to increased deformation. While the polyethylene vest showed better performance for both types of ammunition (especially with the .44 Magnum JHP) the aramid vest demonstrated greater deformation, suggesting that it may be less efficient at redistributing energy around the smartphone. Compared to the baseline test, the presence of a smartphone can reduce the BFS for lower-energy impacts but increase it for high-energy rounds, especially in materials like aramid. An additional and critical observation from the smartphone tests was the occurrence of battery ignition following ballistic impact. In several cases—particularly when the smartphone was impacted by a .44 Magnum JHP projectile—thermal events were observed almost immediately after impact. The lithium-ion battery within the device ignited, producing visible flames and smoke. This reaction is attributed to the rapid mechanical failure of the battery's internal structure, which can lead to a short circuit and thermal runaway when subjected to high-velocity impact. Such ignition events pose a severe secondary risk to the wearer, potentially causing burns or contributing to further tissue damage. Last but not least, in one of the tests involving the polyethylene vest and the .44 Magnum projectile with a smartphone placed beneath, a complete perforation of the vest and the smartphone was observed, as can be seen in Figure 10. This result is particularly concerning, as it again demonstrates that the presence of rigid objects like smartphones can not only increase backface deformation, but in extreme cases, may entirely compromise the structural integrity of the armour. The rigid body likely altered the local stress distribution, creating a focal point for penetration that would not have occurred under standard test conditions.

a) b)

Figure 10. Example of a full penetrating smartphone test (polyethylene vest and the .44 Magnum projectile): a) front side; b) back side

3.3 Military ID tag test

To further evaluate the potential effect of rigid objects commonly worn under ballistic vests, a series of four tests were performed using a polyethylene soft armour vest and a metal military ID tag (see Figure 11) as the underlying object against the .44 Magnum JHP projectile. A skin simulant was positioned in front of the ballistic gelatine block to replicate more realistic tissue interaction. The recorded indentation depths into the gelatine varied significantly, ranging from 29.74 mm to 197.0 mm, as shown in Table 2. The deepest penetration (Test 1) suggests a case where the ID tag likely contributed to either localized failure or redirection of the projectile energy, possibly due to fragmentation or secondary projectile behaviour. On the other hand, the shallower indentations (Tests 2 and 3) indicate scenarios where the armour was able to better distribute the impact, even in the presence of the object. Figure 12 shows the high speed video sequence of test number 2.

Figure 11. Example of the used military ID tag

Table 2. Indentation result on gelatine after the impact.

Test number	Indentation on gelatine (mm)
1	197,0
2	73,2
3	29,74
4	102,15

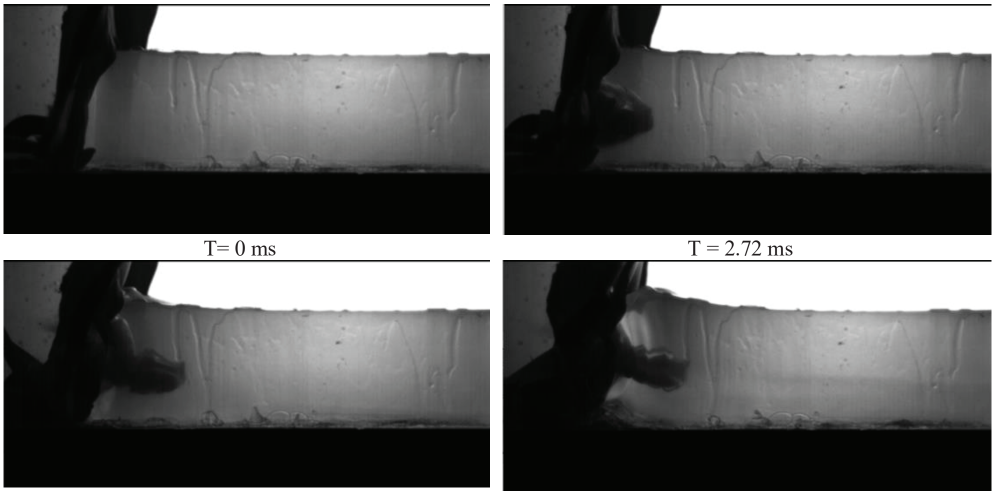

T= 0 ms T = 2.72 ms
T = 4.40 ms T = 12.3 ms

Figure 12. Sequence of high speed video frames for Test number 2

4. CONCLUSIONS

This study investigated the influence of common personal items—specifically a 50 cents euro coin, a smartphone, and a military ID tag—placed beneath soft body armour, using both a modelling clay and ballistic gelatine as witness materials. Three separate experimental setups were used to assess backface signature (BFS), armour performance, and potential wound profiles when these objects interact with ballistic threats.

The presence of a 50 cents coin beneath the body armour significantly altered the vest's performance. In tests with Roma Plastilina No.1, both polyethylene and aramid vests showed increased backface signature, and in multiple cases with .44 Magnum JHP projectiles, full perforation of the vest was observed. Gelatine-based tests further revealed that when no perforation occurred, the coin acted as a secondary projectile and penetrated up to 74 mm into the gelatine. However, in cases of vest perforation, this depth increased to a maximum of 112 mm. The coin itself was deformed but not penetrated, suggesting it played a critical role in concentrating energy and altering the armour's performance.

Smartphones placed beneath body armour also had a significant effect on backface deformation. In comparison with baseline tests, both 9 mm (for aramid) and .44 Magnum (for aramid and polyethylene) impacts showed increased BFS values when a smartphone was present. Notably, for .44 Magnum impacts, one of the polyethylene vest tests resulted in full perforation of the armour. These findings underline the hazardous interaction between electronic devices and ballistic protection, as the "rigid" structure of smartphones—especially components like batteries and metal frames can amplify the localized stress on the vest and increase the likelihood of trauma or penetration. This can potentially lead to higher risks of BABT or even armour failure depending on the energy of the projectile and armour composition.

Finally, in a series of tests, a standard military ID tag was placed behind a polyethylene vest and in front of a ballistic gelatine block, with a skin simulant to replicate more realistic conditions. When struck by a .44 Magnum JHP projectile, the armour was perforated, though the ID tag itself was only deformed. These tests highlight that even relatively thin metal objects can interfere with the ballistic performance of soft armour and may contribute to secondary injuries due to increased penetration depth or fragmentation effects.

Overall, these findings demonstrate that common items worn under body armour can significantly influence its protective performance. They introduce new risks not currently accounted for in standard testing protocols. The study advocates for a reevaluation of certification procedures to incorporate realistic wearing conditions and improve end-user safety. Standardized body armour testing (without objects beneath the vest) does not fully capture real-world threats, as personal items carried by users can dramatically alter armour performance. New testing methodologies could incorporate scenarios with commonly carried objects, as current testing standards may underestimate the risk of BABT and/or perforation when foreign objects are present. Next to that it is important to stress the risks introduced by foreign objects and advise users not to place hard items between the armour and the body. Dog tags may be the only item that could not be place outside the armour.

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