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# An assessment of human performance in stabbing

I. Horsfall\*, P.D. Prosser, C.H. Watson, S.M. Champion

Cranfield University, RMCS Shrivenham, Swindon, Wilts SN6 8LA, UK

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### Abstract

Stab-resistant body armour is now becoming a standard item of equipment for police officers in the United Kingdom. In the UK these are usually required to have a stab resistance as specified by the Police Scientific Development Branch KR42 standard [G. Parker, PSDB Stab Resistant Body Armour Test Procedure, Police Scientific Development Branch, Publication No 10/93, 1993]. There are several other test standards, all of which specify that body armour must resist penetration by a specific blade type delivered at a specific energy level or range of levels. However, the actual range of energy levels specified varies over almost an order of magnitude and the basis for these levels is not clearly defined. This paper describes tests to determine the energy range and characteristics of stabbing actions that might be directed against stab resistant body armour by an assailant. The energy and velocity that can be achieved in stabbing actions has been determined for a number of sample populations. Volunteers were asked to stab a target using an instrumented knife that measured the axial force and acceleration during the stabbing. The maximum energy obtained in underarm stabbing actions was 64 J whilst overarm stabbing actions could produce 115 J. The loads produced on contact with the target often approached 1000 N. © 1999 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Stabbing; Body armour; Impact; Knife

## 1. Introduction

The force required to cause a penetrating wound with a sharp knife has been shown to be between one half and three kilograms in a study by Knight [2]. A spring loaded knife was used to record the forces required to penetrate the skin for cases of the knife being

<sup>\*</sup>Corresponding author. Fax: +44-1793-783076.

E-mail address: horsfall@rmcs.cranfield.ac.uk (I. Horsfall)

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pushed into the skin and for a cadaver being dropped onto the knife. It was found that tightly stretched skin, such as that across the ribs, required about half the force needed to cause penetration into slack skin. Once the skin was perforated the resistance to further penetration was found to be negligible. The most decisive factor in determining ease of penetration was found to be the sharpness of the blade tip. The effect of this far outweighed the effect of all other factors. This area was further investigated by Green [3] and Jones et al. [4], who used more sophisticated measurement techniques to confirm the earlier work and also investigated the effect of clothing. It was confirmed that blade sharpness was extremely important and that only sharp blades could penetrate clothing. Small rigid blades were found to be more penetrative than larger commando or dagger blades. These studies of penetration showed that the skin offered a substantial resistance to penetration but once this was punctured the subcutaneous fat and other underlying tissues were easily cut. This has been confirmed by studies of the cut resistance of skin [5].

Several UK police forces have started equipping all officers with body armour capable of resisting both ballistic and knife attack. This demand has led to the promulgation of a number of test standards for knife resistant armour [1,6–8] in the UK and elsewhere. All the current standards state an impact energy or range of energies over which a test knife is delivered to the armour. Performance is then assessed in terms of the amount of penetration occurring at that energy. The UK standard [1] uses two types of knife delivered over a range of energies between 20 J and 80 J and states that the penetration must not exceed 5 mm at 42 J. A rising scale of penetration is then allowed up to 50 mm at 80 J. The German standard [6] tests at 35 J with a dagger blade and allows no penetration. The USA standard [7] also allows no penetration for a blow delivered at 210 J with an ice pick. The current draft European standard [8] has adopted a multiple level approach with 5 mm maximum allowable penetration at 25 J, 35 J and 45 J.

The wide variation in the test energies selected by various standards bodies has led to some doubt over the validity of the values. There is therefore a need to quantitatively assess the threat from knife attack. Previous studies have investigated the velocity achieved in stabbing [9] whilst the work in this paper concentrates on the energy produced as this is the key variable in test standards. This is a relatively complex task, as not only are there a wide variety of possible weapons but also a highly variable human element in powering the weapon. In this study a method is described for measurement of human performance in stabbing, and preliminary data is presented.

## 2. Procedure

As all current standards define the energy of a blow that must be stopped by the armour, the primary measurement required is of impact energy. It is also useful to know the force and velocity history of the impact event. In order to assess the ability of a person to deliver a knife it is necessary to measure a number of basic parameters, namely the force that can be applied and the speed with which it is applied. From this basic data it is possible to derive most of the required results including the total energy



Fig. 1. Instrumented knife.

of the impact and the impact velocity. In this work it was decided to use an instrumented knife to measure the force and acceleration during an impact with a standardised target.

The instrumented knife is shown in Fig. 1 with a 'commando' style blade<sup>1</sup> which was used in all tests. The basic blade is a diamond section dagger of 120 mm length, although this was cut down to 80 mm for the tests. A new blade was used for each series of tests although earlier substitution was sometimes required due to damage or blunting of the blade tip. The blade was held in a clamp on the front of the instrumented knife. A piezoelectric load washer positioned behind the blade measured the axial force on the blade during impact. On the rear of the hilt was a single axis accelerometer to measure deceleration during impact. A sabre guard was used to protect the hand of the subject. The transducers were connected to a transient recorder, in this case a Rosand Precision Ltd. control unit.

The force transducer was calibrated using a procedure similar to that described by Money and Sims [10]. A weight was suspended from the blade clamp by a wire. The handle was then dropped, allowing the assembly to go into free fall and thereby emulating a compression pulse at the transducer. The accelerometer was supplied with a factory fixed calibration, although this was confirmed using a calibrated shaker table.

All tests used a standard target consisting of a 12 layer Aeroflex<sup>®2</sup> sheet. This is a semi-flexible Kevlar® fibre composite consisting of plain woven layers in a thermoplastic binder. This material is not a candidate armour material, but was chosen to give a

<sup>&</sup>lt;sup>1</sup>Supplied by H.M. Slaters Ltd., Sheffield, UK.

<sup>&</sup>lt;sup>2</sup>Supplied by Aero Consultants UK Ltd., Cambridge, UK.

degree of resistance to penetration without actually preventing it. The target was mounted on a Plastolena® backing block of a type usually used for ballistic testing of body armour. This provided support to the target without interfering with the penetration process.

After each test the data was downloaded from the transient recorder to a personal computer spreadsheet for processing. The basic data consisted of instantaneous values for force (F) and acceleration (a). For most tests 380 data points were recorded on each of the two measurement channels over a period of 50 ms. Longer recording periods and high-speed video recording were used on some trials in which it was shown that the knife was arrested within 50 ms. Therefore the impact velocity or the velocity at any point after impact was determined by summing the acceleration data from the last point backwards.

$$V_{\rm impact} = \sum_{i=380}^{i=0} a_i$$
 (1)

The instantaneous velocity  $(\Delta v)$  in metres per second, is then multiplied by the time interval between data points in seconds, to give the distance travelled in each time interval  $(\Delta x)$  in metres.

$$\Delta x = \Delta v \cdot \frac{0.05}{380} \tag{2}$$

The instantaneous energy in Joules, was then calculated as the distance travelled  $(\Delta x_i)$  multiplied by the force. This was summed to determine the total energy of the stab (*E*) in Joules.

$$E = \sum_{i=0}^{i=380} F_i \cdot \Delta x_i \tag{3}$$

For each test it was therefore possible to determine total energy and impact velocity. It was also possible to show the force, acceleration and velocity history of the event. A typical result is illustrated in Fig. 2.

In order to verify the calculations and assumptions the knife penetration into the target was measured after the test and compared to the total calculated total displacement. These were found to be in agreement.

### 3. Results

The groups of volunteers used in this work included students from the Royal Military College of Science (RMCS), police officers and staff from Gloucester and Hertfordshire Constabularies and visitors to the International Police and Security Exhibition 96. In most test groups each subject was asked to perform one underarm action stab (Fig. 3). In



Fig. 2. Velocity, force and acceleration profiles for a 42 J underarm action stab.

tests at RMCS each subject was asked to stab twice using an underarm action, and some subjects from each group were also asked to stab using an overarm action (Fig. 4). No other guidance on technique was given to the subjects.

Figs. 5 and 6 show the accumulated data for underarm and overarm action stabs respectively, the data is summarised in Table 1. The larger data set in Fig. 5 provides a more even distribution, however, it is possible to see a large difference between the two actions. There was a significant difference between the performance of male and female subjects with the average energy for female underarm action stab being 10.8 J compared to 28.6 J for males. Little significant difference was observed between different male groups, the RMCS students and Gloucestershire police groups performance being close to the overall values.

## 4. Discussion

The interaction between the knife and target is illustrated in some detail in Fig. 2. In this test the knife had an impact velocity of 8 ms<sup>-1</sup>. On contact with the target it was rapidly decelerated leading to a peak deceleration of 800 ms<sup>-2</sup>, whilst force rose more slowly to an eventual maximum of 800 N. The actual shock loads to the test subject wrist would be somewhat lower than this as the subjects grip onto the hilt was not completely rigid. However the loads are significant and in the case of more effective armour might lead to damage both to the knife and the wrist of the attacker. Most subjects were seen to continue pushing on the knife after impact which is indicated by



Fig. 3. Underarm action stab.

the long tail on the force profile. The muscular effort is in the region of 200 N but was insufficient to overcome the frictional resistance of the knife embedded in the target.

In this study the mean terminal velocity of the knife was  $5.8 \text{ ms}^{-1}$  for underarm stabs and  $8.5 \text{ ms}^{-1}$  for overarm stabs. These values compare well with results of Miller and Jones [9] who determined mean velocity values of  $5.8-6.3 \text{ ms}^{-1}$  and  $8.5-9.2 \text{ ms}^{-1}$ respectively. In a study by Tan et al. [11] the terminal velocity was found to be 14 ms<sup>-1</sup> although the maximum energy level measured was no greater than 42 J. The higher velocities recorded by both the previous studies are probably due to the different weight of knives used. The knife used by Tan et al. [11] weighed 175 g and that by Miller et al.



Fig. 4. Overarm action stab.

[9] weighed 192 g, whilst the knife used in this study weighed 600 g. Assuming a similar muscular effort a heavier knife will have a lower terminal velocity than a light knife but the same kinetic energy.

The mean, 95-percentile and maximum values of energy and velocity are shown in Table 1. The practical significance of the mean values is questionable as each group of volunteers contained some individuals that performed very poorly. Similarly the maximum values obtained were from exceptionally fit and well-trained individuals who may not be representative of the wider population. However, it may be that individuals willing to use a knife against a police officer may fall into a similar category. The



Fig. 5. Histogram of stab energy for underarm action stabs.

95-percentile value may give a realistic indication of maximum required armour performance. The value of most significance is probably the 95-percentile for all underarm stabs, which was 54.4 J. This is significantly greater than that specified in the current UK test standards (42 J) [1]. Only the USA (H.P. White) standard [7] specifies significantly higher energy levels and this was set against a double handed overarm



Fig. 6. Histogram of stab energy for overarm action stabs.

Group	Number of tests	Mean energy (J)	95% energy (J)	Maximum energy (J)	Mean velocity (ms <sup>-1</sup> )	95% velocity (ms <sup>-1</sup> )	Maximum velocity (ms <sup>-1</sup> )
All underarm	157	26.4	54.4	63.4	5.8	8.2	10.1
All overarm	46	46.1	77.3	114.9	8.5	11.0	11.6
Male, underarm	142	28.1	54.9	63.4	6.0	8.3	10.1
Female, underarm	15	10.8	22.4	30.9	4.6	6.0	7.4
RMCS, underarm	32	26.8	50.9	57.5	6.1	8.3	9.4
Gloucestershire police, underarm	60	31.6	57	64	6.1	7.8	9.0

Table 1 Summary of performance data

action stab. However there are a number of factors that effect the significance of the measured values to practical armour systems.

The loads generated on the knife were approximately 1000 N for the higher energy stabs. This was for armour that allowed 45 mm of penetration at 40 J. Practicable armour systems that meet current penetration limits would produce far higher loads so that the knife or attacker's wrist might be damaged. This might mitigate the effect of higher energy stabs.

The primary purpose of this study was to provide information on the energy levels required for testing stab resistant armour. Although both underarm and overarm action stabs were analysed, a greater importance has been placed on the underarm action for two reasons. Conventional designs of body armour afford poor protection from an overarm stab as both the shoulders and the neck are difficult to protect. Also the overarm stab offers some chance of active defence whilst an underarm action can be relatively covert and is consequently more difficult to defend against. For this reason the underarm stab is seen as the major threat, and one that can be countered by wearing armour.

The validity of the data to the overall population and to potential attackers must be considered. A number of factors, both psychological and technical, will limit the accuracy of the data. The volunteers in these tests were operating under relatively relaxed conditions. However the military and police volunteers might be expected to be able to produce reasonable levels of controlled aggression on demand. In addition, there was a considerable element of competition and peer pressure during the tests that were often conducted with groups of volunteers. The results of the tests were known after each test so that there was an incentive to beat previous volunteers' scores.

The instrumented knife had a large hilt with a disc shaped guard at the front that allowed very good transfer of axial load from the hand. It has been stated [12] that the knives used in real assaults are often relatively small in order to allow concealment. This data might therefore represent an overestimate of the forces that could be generated with a more conventional knife hilt particularly that of a small kitchen or folding knife.

It is necessary to consider the effect of the target on the measured stab energy. The target used in this study allowed typical penetrations of 45 mm at 40 J which is considerably greater than that which would be achieved in a commercial armour. However, a soft target was needed in order to eliminate the chance of injury to the test

subjects. Apart from preventing injury to the test subjects this also allowed the subjects to stab without fearing injury. This was felt to be important as a large number of body armour designs are covert and hence an attacker would not know that the target was armoured. It is therefore necessary to simulate as nearly as possible the highest energy impact that the might be generated.

In order to determine the effect of the target used on the measured energy it is necessary to look in detail at the impact event. It can be seen from Fig. 2 that very high loads are generated on the knife, which are greater than could be generated by direct muscular effort. These high loads are primarily generated by deceleration of the knife and later the hand and arm. An underlying and relatively small muscular effort is seen in the latter stages of the event once the knife has been arrested. Hence the energy measured during the impact event comes from two principal sources: the kinetic energy of the knife/hand/arm system and the muscular force (work) expended during the penetration event. A very effective armour might allow virtually no penetration, in which case only the kinetic energy component would be present. Whilst a soft target that allowed large penetration event.

The manual work expended on the target will be the product of the muscular force and the total distance over which the knife travels during the impact. The knife travel will be the sum of penetration through the armour (typically 45 mm), the target thickness (5.5 mm), and target movement into the backing (10 mm), giving a total of 60.5 mm. Examination of the force data (Fig. 2) shows a residual force of approximately 200 N, which can be taken as the underlying muscular effort during the impact event. If the total knife movement during impact were taken as 60.5 mm and a constant muscular force of 200 N then the muscular work done on the target would be 12 J.

It can be seen that the measured ability of the subjects will increase with greater penetration into the target or greater blunt trauma (movement into the backing). It is not possible to test very effective armours, as the impact forces on the knife would be likely to cause injury to the subject. Therefore a relatively low resistance material was used for these tests. Practicable armour systems must not allow more than 5 mm penetration to meet current UK specifications [1], however these tend to be relatively flexible and consequently allow more movement of the armour into the backing material. Consequently the total energy which might be expended against an armoured target would not differ significantly from the range of values measured in this work. However, the energy values reported in this study may be underestimates of the maximum that might be achieved against a very soft or poorly supported target.

### 5. Conclusions

A method has been demonstrated for the measurement of the stabbing ability of a small population. This has produced measurement of typical stabbing ability in terms of energy, velocity and force.

For underarm stabbing action the maximum energy achieved was 63 J and the 95-percentile energy was 54 J and the mean was 26 J. For an overarm stabbing action

the maximum energy was 115 J and the 95-percentile energy was 77 J and the mean was 46 J. The typical terminal velocity of the knife was  $6-10 \text{ ms}^{-1}$  although a higher velocity could probably be achieved with a more conventional and lighter knife. Impact loading on the knife often approached 1000 N even against a relatively soft and easily penetrated armour.

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