Kinetic Non-Lethal Weapons

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Introduction

When Koene told a Belgian colleague that he had been asked to contribute to an issue of *NL-ARMS*, he understood the subject of this series was 'non-lethal' arms. It was explained that this was not the case. However, this is how the idea of this contribution was born.

NATO defines so-called 'non-lethal' weapons as follows (NATO mission statement, October 13, 1999):

> *Non-lethal weapons are weapons which are explicitly designed and developed to incapacitate or repel personnel,* ***with a low probability of fatality or permanent injury****, or to disable equipment, with minimal undesired damage or impact on the environment (our emphasis).*

According to the United Nations Institute for Disarmament Research (UNIDIR) non-lethal weapons (NLWs) can be defined as:

> *Non-lethal weapons are specifically designed to incapacitate people or disable equipment, with minimal collateral damage to buildings and the environment; they should be discriminate and not cause unnecessary suffering; their effect should be temporary and reversible; and they should provide alternatives to, or raise the threshold for, use of lethal force.*

Usually, in a definition of a weapon it is explained what a weapon should do, while the definitions of non-lethal weapons explain what a weapon should *not* do. In addition, these definitions have subjective and vague aspects: 'low probability' and 'unnecessary suffering' are not specified. As is apparent from these descriptions, the predicate non-lethal does not imply that these weapons cannot cause death, most important is the *intent* that they are non-lethal in case they are used and that death caused by the weapon employed is *as unlikely as possible*. Of course, there are weapons, which are 100% lethal, but thus far unfortunately there are no weapons, which are 100% non-lethal. Therefore, some people prefer using 'less-lethal' instead of 'non-lethal'. Non-lethality is dependent on the inherent nature of the weapon, the way a weapon is used and the vulnerability of the opponent or equipment. Several types of non-lethal weapons exist, for example: biological, electrical, chemical, electromagnetic and acoustic weapons.

In the last decade, the interest in non-lethal weapons has increased considerably. This is a consequence from both progress in non-lethal technology and growing interest from military forces and civil police for more sophisticated and proportional responses to violence. Many disciplines are involved in the study of non-lethal weapons. These include medicine, i.e. effectiveness, risks and treatment; legal, i.e. compatibility of the law and technology, legal protection for the professional user; social sciences and philosophy, i.e. dynamics of groups, perception of limited lethality and ethics; and ballistics, i.e. 'classical'

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ballistics, evaluation, mechanisms and projectile-target interaction and innovative developments.

While non-lethal weapons are a vast field, the topic of this paper is limited to so-called *kinetic non-lethal weapons* that can be applied to stop people performing harmful actions. While sometimes details are mentioned on the weapon used, the focus is on terminal ballistics, i.e. the projectile-target interaction. Well-known examples of non-penetrating kinetic NLWs projectiles are: baton rounds, beanbags, fin stabilised rubber projectiles, multi-ball rounds, rubber ball rounds, and sponge grenades. Munitions are fired at the target with relatively low velocity. As a consequence the maximum damage to people is limited; at the utmost they may be wounded.

Figure 1. The FN303 projectile (left) and the Bliniz projectile with its cartridge (right)

This is an orienting paper about kinetic non-lethal weapons. One of its purposes is to help the non-specialist reader better understand scientific and technological aspects of these new weapon systems. First, physical parameters and experimental methods are reviewed. Next, performance tests of two existing non-lethal weapon systems are shown, i.e. the FN303 and the Cougar with Bliniz projectile (Fig. 1). Results are compared with other projectiles: four different balls and a beanbag. They sketch the state-of-the-art and challenges of this developing field. Finally, a conclusion and summary is given.

Physical parameters and experimental methods

Impact on a human body is characterised by energy transfer to the body by an impacting projectile. This may cause injury. In evaluating the effect of projectiles, three domains are relevant, viz. physics, biomechanics and medicine. In order to understand these evaluations several physical parameters and experimental methods have to be understood. Next these parameters and methods are discussed.

Kinetic energy, momentum, impact area and energy density

Studies and evaluations of (possible) injury are often based on four physical parameters:

1. The kinetic energy of the projectile is equal to:

$$E_k = \frac{1}{2} m v^2 .$$

2. Its momentum given by:

   $$p = mv,$$

   with m the mass of the projectile and v its velocity.
3. The (effective) cross-sectional impact area:

   $$A = \pi\left(\frac{d}{2}\right)^2 .$$

   (Note that the diameter d of the cross-sectional area may be different from the calibre of the projectile, for instance: in case of deformation it is larger.), and
4. The energy density e, i.e. the ratio of the kinetic energy E_k and the effective impact area A:

   $$e = \frac{E_k}{A} = \frac{2mv^2}{\pi d^2} .$$

Usually, experimental results are plotted or tabulated as functions of both kinetic energy E_k and energy density e.

Lyon et al. [1] mention that in 1975 a reasonable fit was accomplished by Clare et al. using an empirical four-parameter model, which included the projectile mass (m), the velocity (v), the projectile diameter (d) and the target mass (M). The parameters are plotted using the natural log of the projectile kinetic energy (E_k) vs. the log of the product Md. This model was extrapolated from the mass of the target animals to that of a typical adult male (70 kg). Fig. 2 includes two discriminant lines dividing the graph into three regions, viz. (1) a zone of low lethality, (2) a zone of mixed results, and (3) a zone of high lethality. This illustrates an important and difficult question in non-lethal weapon research: how can we minimise lethality of effective weapons?

The four-parameter model (Fig. 2) was later expanded into another empirical model, viz. a five-parameter model, the so-called blunt criterion (BC) [2]:

$$BC = \ln\left[\frac{\frac{1}{2}mv^2}{M^{1/3}Td}\right],$$

with T the thickness of the body wall of target. As the equation shows, the numerator represents the kinetic energy of the ammunition. The denominator contains those characteristics of the target that have been found to be related to its ability to tolerate the energy of impact.

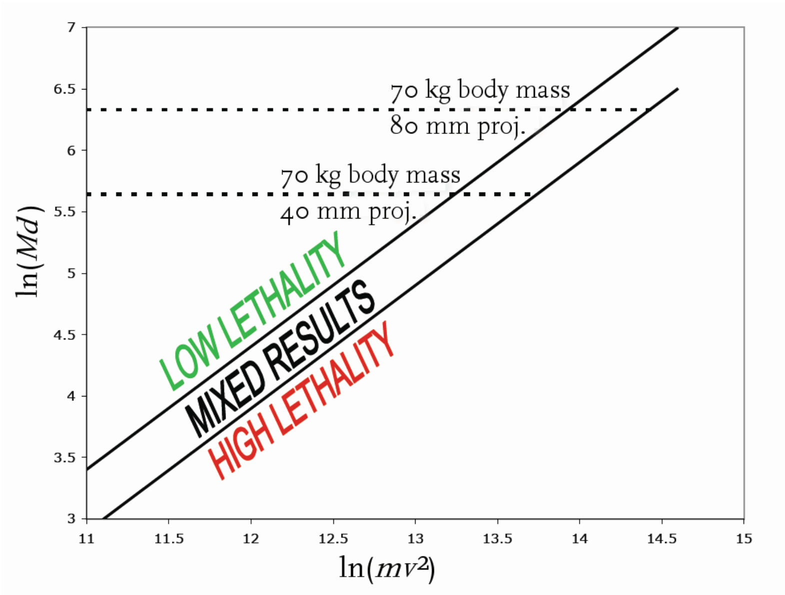

Figure 2. The empirical Four-Parameter Generalized Model for blunt impact, adapted from Lyon et al. [1]. On the vertical axis the log of the product of target mass M (kg) *and projectile diameter d* (cm) *is shown. On the horizontal axis the log of the product of projectile mass m* (g) *and velocity v* (m/s) *squared is shown (see text).*

Tissue and skin simulants
Animal tests are somewhat old-fashioned, for nowadays it is thought that tissue is inferior to a good simulant (MacPherson [3]), because a bullet impact on tissue has no special effects. Tissue is inhomogeneous and often gives irreproducible results. A good simulant is homogeneous, because it allows experiments to be repeatable and reproducible. Also, it should be practical, i.e. relatively easy to work with and available at acceptable cost. The most difficult requirement though is that of dynamic equivalence of simulant to tissue. Forces are produced on a bullet when it hits tissue and a good simulant should produce very similar forces on the bullet in the same conditions.

According to Viano and King [4] the biomechanical response of the body has three components: (a) inertial resistance by acceleration of body masses, (b) elastic resistance by compression of stiff structures and tissues, and (c) viscous resistance by rate-dependent properties of tissue. Three classical experimental evaluation methods exist, i.e. (1) clay back face signature tests, (2) ballistic gelatine tests, and (3) biomechanical surrogates (crash dummies) tests. In the following sections they are discussed.

1) Clay back face signature
This method examines the cavity created in standard materials, like plasticine, due to impact of the kinetic projectile. The ultimate objective is to determine the potential level of injury of a human being. In case the cavity depth is higher than a certain critical value, the result is a failure because the (possible) injury is considered too severe. The method is used to evaluate body armour.

2) Ballistic gelatine
Another method for the evaluation of the level of injury uses ballistic gelatine. Usually 10% or 20% (weight) is used. This method has been extensively used to model

penetrating impacts. For penetrating impacts 10% gelatine is considered better [3]. This material can be used to determine the rate of energy deposition and the total energy within a target by a penetrating projectile. High-speed cameras can illustrate the degree of temporary deformation and reveal other relevant impact phenomena.

However, this generally accepted procedure for penetrating projectiles has to be adapted and validated for the study of the effect of **non-penetrating** projectiles. Moreover, body tissues have a variable sensitivity for injury and resistance to impact. For her research of ballistic impact of the thorax Bir [5] concluded that 20% ballistic gelatine was better than 10% for both deflection and force data were closer to the human response. Moreover, in two of the impact conditions the 10% ballistic gelatine was penetrated. This indicates that ballistic gelatine and clay have possibilities as simulants in testing non-penetrating ballistic impacts, but with some limitations.

In testing kinetic non-lethal weapon systems it is necessary to include skin in the model. The FN303 projectile, for example, penetrates into gelatine but does not penetrate human skin. In Table 1 possible skin and tissue simulants for testing less lethal projectiles are shown. Moreover, one would also like to account for the effect of different types of clothing. We come back to skin and skin simulants later.

Table 1. Skin and tissue simulants. Ballistic gelatine is most commonly used as a soft tissue simulant.

Skin simulants	***Tissue simulants***
Pig skin	*Plasticine (clay)*
Rubber	*Ballistic gelatine, 10% or 20%*
Polyurethane [6]	*Soap*
Chamois leather [7,8]	

3) Biomechanical surrogates

In biomechanics surrogate tests have been developed as tools for injury evaluation for example for automotive industry (crash dummies), sports and aviation. A well-known method of analysis to determine the injury level to the thorax is the so-called viscous criterion (VC). This response is intended to predict the severity of soft tissue injury and cardio respiratory dysfunction caused by blunt impact. The method utilises measurements taken from the surrogate undergoing an impact event (see Fig. 3). The time-dependent product of the velocity of chest deformation (V in m/s) and the amount of (chest) compression (C in %) forms the figure VC [1,2,5]. The probability and level of injury can be assessed using the maximum VC, $(VC)_{max}$. So, according to this criterion not only the *amount* of compression is relevant, but also the *rate* of compression.

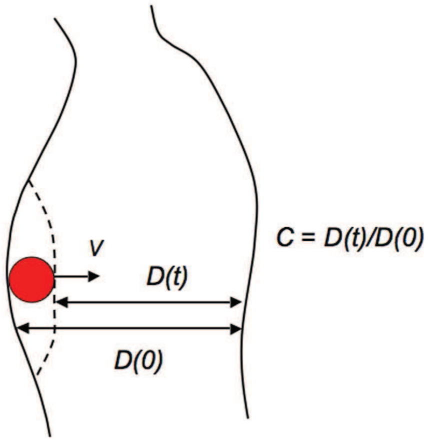

Figure 3. Sketch of chest deformation (V) and chest compression (C). Note that here V is the deformation velocity of the chest, not the velocity of the projectile.

It should be emphasised that impact phenomena associated with non-lethal projectiles are 'low-mass' and 'high-velocity', while 'high-mass' and 'low-velocity' impacts are typical for automotive collisions (Fig. 4). One of the challenges in this field is to validate tests for different non-lethal projectiles using test dummies. A factor that may complicate modelling these biomechanical experiments for blunt ballistic impacts is the dissipation of energy of the rounds upon impact. This method seems promising, also because one can measure forces on the test dummy during impact processes.

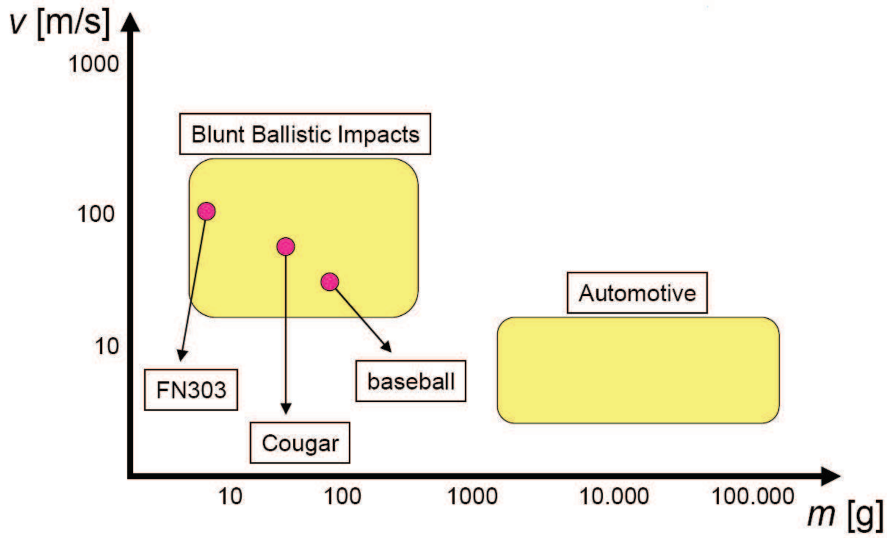

Figure 4. Logarithmic figure of projectile velocity v versus mass m adapted from Bir [5], with own data added. Note the differences in mass and velocity for automotive collisions and 'non-lethal' ballistic impacts.

Young's modulus and non-elastic behaviour of tissue

When a load is applied to a material, it undergoes deformation because the atomic bonds bend, stretch or compress. Tissue is no exception. Because bonds have been deformed they try to restore themselves to the original position. This generates a stress in the material. The applied force (F) causes a deformation (strain) and a restoring stress in the deformed bonds. Stress is a measure of a material's ability to resist the applied force. It is defined as $\sigma = F/a$, with F the force on the material and a the area of a cross-sectional plane for the type of stress. The strain (ε) is defined as $\varepsilon = \Delta r/r$ with Δr the change of distance in a specific dimension with r the original value. The strain is often expressed as a percentage and the stress has the unit of pressure, Pa in SI units. Initially, many materials deform elastically. In this region the stress is proportional to the strain ε:

$$\sigma = E\varepsilon ,$$

where E is the modulus of elasticity or the *Young's modulus* of the material. Table 2 gives the Young's moduli of selected human tissues.

Table 2. Young's modulus of selected tissues and simulants.
The yield strength is the stress at which the material begins to deform plastically.

Tissue	*Young's modulus E kPa*	*Reference*
Human skin	*20-100*	*10*
	420-850	*11*
	200-300	*12*
Polyurethane (skin simulant)	*182 (yield strength: 2.583 MPa)*	*6*
Breast (fibroglandular)	*1.8*	*13*
Muscle	*$0.675 \cdot 10^{6}$*	*14*
Soap	*$21.45 \cdot 10^{3}$ (yield strength: 1.63 MPa)*	*15*
Gelatine 20%	*96 (0.001 s^{-1} strain rate)* *124 (0.01-1 s^{-1} strain rate)*	*16*

Stress (σ) of a material should remains below a critical stress limit, the tensile strength; this is the point where a material breaks. Biological materials usually show different mechanical behaviour than more traditional materials. For instance (unlike homogeneous materials) skin has no unique, single, Young's modulus. This property varies depending on the strain applied. Typical behaviour for biological materials is a stress-strain diagram showing an *elastic part*, which may be linear or non-linear, and a history dependent *inelastic part*.

Variation of Young's modulus with strain is clearly illustrated in the research of Snedeker et al. [9] on kidney tissue. They used four descriptive material parameters to describe the behaviour of porcine and human kidney capsules, viz. ε_{max}, σ_{max} and E_1 and E_2. The ultimate strain and stress were denoted by ε_{max} and σ_{max}, respectively. E_1 was defined as the low-strain apparent modulus and was calculated from the slope of the best linear fit between 0 and 5% of the ultimate strain. The high-strain apparent modulus E_2 was defined similarly between 60% and 80% of the ultimate strain. 25 Tests were performed. For human kidney capsules E_1 and E_2 were 6.7 ± 1.9 MPa and 41.5 ± 11.1 MPa, respectively. ε_{max} and σ_{max} were equal to $33.4 \pm 6.5\%$ and 9.0 ± 2.9 MPa, respectively.

Ballistic gelatine has a Young's modulus of approximately 100-150 kPa. The dependence of the modulus on strain rate suggests that ballistic gelatine has a significant visco-elastic component to its mechanical behaviour. This is confirmed by dynamic measurements from rheometer experiments [16]. Ballistic gelatine has similar properties as the soft tissues in Table 2, which is of course the reason why it is often used as a simulant.

Skin penetration

An aspect often ignored or discounted in wound ballistics is that of the initial penetration of human skin before the main wound is formed in the under-lying tissue. The skin should be taken into account in studying the effects of kinetic non-lethal weapons. In Table 3 data adapted from Warlow [17], threshold velocities and energy densities are given for human skin perforation.

Table 3. Threshold velocity and energy density for human skin perforation (adult upper thigh skin). Data were adapted from Warlow [17].

Composition	Mass g	Sectional density g/mm^2	Threshold velocity m/s	Energy density J/cm^2
4 mm – 0.157 in *Spheres*				
Glass	0.08	0.0064	198 ± 23	9.7
Steel	0.26	0.021	126 ± 14	13.1
Brass	0.31	0.25	121 ± 13	14.5
4.5 mm – .177 in *Lead Pellets*				
Sphere	0.54	0.034	110 ± 12	20.7
Spire point	0.56	0.035	109 ± 12	20.9
Flat-nosed	0.49	0.031	136 ± 17	28.3
Hollow point	0.44	0.028	133 ± 18	24.5

For experimental ballistic research one is searching for good simulants for human skin. Fresh abdominal pigskin of 3-4 mm thickness has been shown to give the most comparable results. However, it is difficult to control its thickness, to store it and in obtaining convenient supplies. Haag [18] found that car inner-rubber tube of 1.3-2.0 mm thickness gave the next best results. This material is easy to obtain and offers no difficulties in storage. One can also think about latex rubbers of well-defined thicknesses like the type used for surgical gloves. Tests by Haag [18] and by Salziger [19] using such thin barriers in front of the gelatine test blocks only showed significant results in the case of 9 mm and .38 in handgun bullets at velocities below 100 m/s.

In a recent paper by Jussila et al. [21] the target values for ballistic skin simulant (30 year old man, chest) were a tensile strength (the point where material fails) of 180 ± 20 kPa, a threshold velocity of 94 ± 4 m/s and break at an elongation of 65 ± 5%. They found that the best skin simulant evaluated was semi-finished chrome tanned upholstery “crust” cowhide of 0.9-1.1 mm nominal thickness. Its threshold velocity was 90.7 m/s, tensile strength 20.89 ± 4.11 MPa and elongation at break 61 ± 9%. These values are close to the average for human skin. Of the synthetic materials, the authors considered 1 mm of natural rubber as a good possible skin simulant. However, its reported theoretical threshold velocity was only 82.9 m/s [20].

Di Maio et al. [21] performed a series of tests to determine the velocity necessary for lead air gun pellets (calibres .177 and .22) and calibres .38 bullets to perforate skin on human lower extremities. For calibre .177 air gun pellets of 8.25 grains (gr) a minimum velocity of 101 m/s was required. The energy per area was 18.2 J/cm². Calibre .22 air gun pellets weighing 16.5 gr perforated at 75 m/s. The energy per area was 12.8 J/cm². A round nose calibre .38 lead bullet weighting 113 gr perforated skin at only 58 m/s. The energy per area was 18.9 J/cm². These values are in the same range as the values in Table 3.

One should understand that an important reason why velocity (kinetic energy) and penetration are not always correlated is that damage is not due to energy absorption, but to too much stress (σ_{max}). In the case that the strain is above a certain critical limit (ε_{max}) tissue is damaged. Moreover, for the threshold velocity the area (calibre), projectile material and shape should be taken into account.

Statistical injury risk assessment

In injury risk assessment the injury probability p is related to a biomechanical response x. With a special case of the logistic function, i.e. the standard *logistic function*, the injury probability is related to the response by

$$p(x) = \frac{1}{1 + \exp(\alpha - \beta x)} ,$$

where α and β are parameters derived from statistical analysis of biomedical data. This function gives a sigmoidal relationship with three distinct regions: for low biomechanical response levels there is a low probability of injury and, similarly, for very high levels the risk asymptotes to 100%. In the transition region between these two extremes there is risk proportional to the biomedical response. A sigmoidal function is typical of human tolerance because it can describe the distribution in weak through strong subjects in a population exposed to impact.

An example of use of a logistic function to assess injury is the following. The example is about lung injury due to non-penetrating impacts with stiff PVC cylindrical masses with 37 mm diameter but varied in mass from 0.069 to 3.0 kg. Determination of the lung weight and the volume of contusion measured injuries quantitatively. The ratio of lung weight and the expected healthy lung weight determined a parameter Q_i. Impacts resulting in a Q_i greater than 1.5 were considered as severe and impacts with a Q_i of less than 1.5 were considered minor to moderate. Experiments were performed and reported by Cooper and Maynard [22] and further analysed by Bir et al. [5,8] using logistic regression to relate these data to a single injury criterion. Deflection data was used to explore the viscous criterion VC as a means for predicting lung injury. The logistic function calculated is shown in Fig. 5. The R-value shows how strong the correlation is between the biomechanical response parameter $(VC)_{max}$ and the prediction of Q_i. The maximum value of R is 1 and represents a high correlation.

Based on this analysis one can see a $(VC)_{max}$ of 3.5 m/s will result in a 50% chance of sustaining a severe lung injury. A 25% risk of severe lung injury is predicted with a $(VC)_{max}$ of 2.8 m/s.

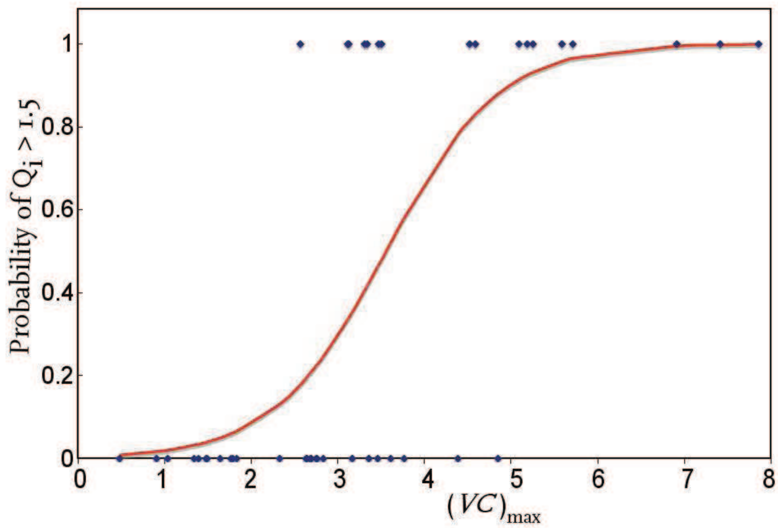

Figure 5. Logistic regression curve probability of $Q_i > 1.5$ versus $(VC)_{max}$ and experimental data points. The logistic function p calculated had $\alpha = 5.48$ and $\beta = 1.54$ (Quality fit: $X^2 = 25.085$, $p = 0.0000$ and $R = 0.67$). Data points with $Q_i > 1.5$ are 1 and points with $Q_i \leq 1.5$ are 0. Source data were provided by Cooper and Maynard [22] and Bir [5].

Human vulnerability models

At impact, a projectile will transfer energy and momentum to the human tissue. Depending on energy, momentum and impact location this will have an injurious or non-injurious effect. Numerical human vulnerability models can simulate the effect at impact on a human body. These models contain a detailed description of human anatomy. Through shot line analysis the damage to tissue involved along the penetration channel can be calculated as a function of the energy transferred to the tissue as a result of impact. For non-penetrating events, such as in the case of non-lethal projectiles, these models describe the stress waves propagated through the tissue. The stress waves are a result of the impacted projectile and can cause tissue damage. Computer codes such as FRAG/MAN IV and ComputerMan may thus provide *estimates* of the level of incapacitation corresponding to the probability that a targeted person will abort his intended actions (Griffioen-Young et al. [23]). However, these human vulnerability models are based on lethal data. Whether they are still valid enough for NLWs is an open question.

Performance tests of two existing NLW systems

Next, performance tests of two modern non-lethal weapon systems will be discussed, viz. (1) the FN303 weapon system and (2) the Cougar launcher with Bliniz projectile.

Experimental set up

The weapon that launches the 'non-lethal' missile is placed on a platform. The target is at a distance of 10 m. This is a typical distance for use of kinetic non-lethal weapons. As simulants for the human body plasticine is used. If test materials are penetrated, both diameter and depth of cavities are determined. Radar is used to measure both muzzle velocity and impact velocity [24].

Projectiles

The FN303 is developed by *FN Herstal* and operates with compressed air. Projectiles are stored in a rotating magazine with a capacity of 15 cartridges. The FN303 is a semi-automatic weapon and has a manual safety. The FN303 launches a fin-stabilised projectile that is made of brittle plastic. It contains bismuth granules and an amount of propellant, dependent of the type of projectile. All FN303 projectiles are non-toxic and environmentally friendly. The projectiles are designed to break at impact and thus avoid the risk of penetration wounds. The calibre is 17.3 mm, the mass is 8.5 g and the effective mass is 0.78 g. According to the manufacturer, the maximum effective range is 50 m because of the fin-stabilised design. The primary effect of the projectile is trauma; the shock immediately neutralises a person. Secondary effects can be caused by a chemical charge in the projectile, for instance *Oleoresin Capsicum* (OC) better known as pepper spray.

Figure 6. Cougar (left) and FN303 (right) launchers

The *Cougar* is a grenade launcher of the 'break-open'-type, developed for the firing of gamma grenades developed by Alsetex for preservation of order. The weapon can be used for both direct and indirect firing. Here direct firing is studied. The projectile is a flexible *Bliniz* projectile consisting of an amount of inert powder (flour) surrounded by a latex shell. The projectile is separated from the propellant by a plastic wad serving as a piston when the round is discharged; 4 sabots guide the projectile. When the muzzle is reached the elements serving for propulsion and guidance are removed from the projectile. Because of their relatively small mass and their relatively large surface they lose speed very quickly. Its calibre is 56 mm and the mass 82 g. The objective of the projectiles is trauma, the shock neutralises a person. The soft projectile transfers (a part of) its energy as it flattens upon impact; it folds around the shape of the struck area. According to the manufacturer, the effective range for direct fire with a Cougar launcher is between 5 and 25 m.

Other projectiles investigated are a 6.2 g so-called '1' rubber ball and a 0.60 g '15' flexible rubber ball fired with a shotgun mounted on the platform. The muzzle velocity is between 190 and 195 m/s. A beanbag is a bag made of cotton with 40 g lead in cartridges of 20 mm diameter. Its diameter of impact is variable up to 26 cm^2. Also, experiments are performed with tennis and squash balls. Other than with other experiments, targets are positioned at 5 m to improve the performance. Impact velocities of about 55.5 m/s are reached [24].

Results and Discussion

In Figs. 7 - 9 results for the FN303 and Bliniz (Cougar) projectiles are shown compared to a few other characteristic 'non-lethal' projectiles.

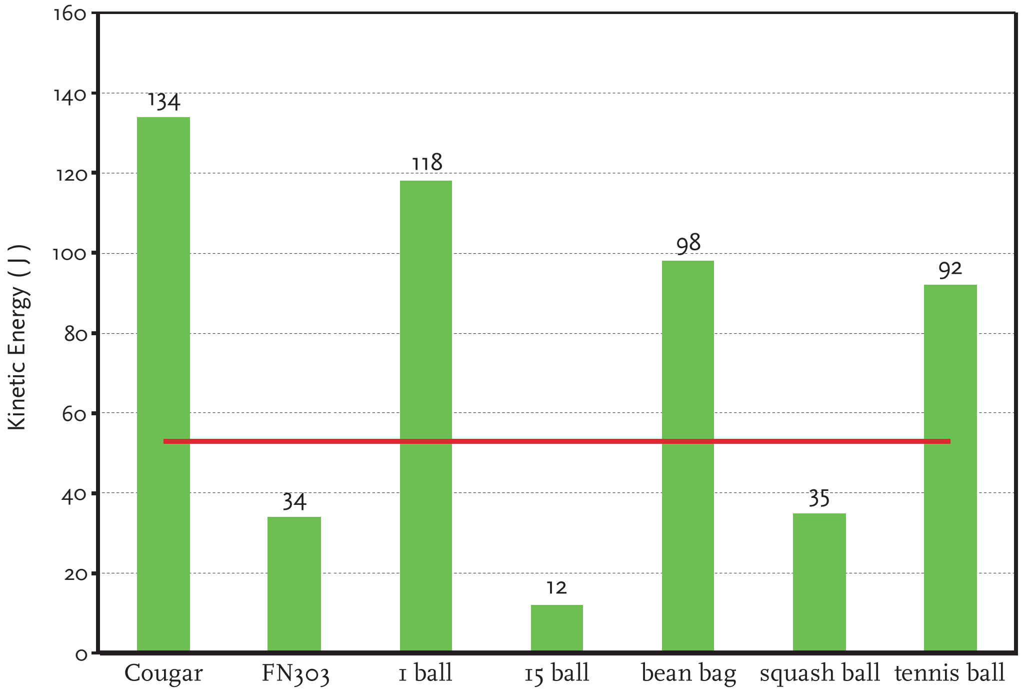

Figure 7. Kinetic energies of different projectiles. The red line represents a threshold value. Here 53 J is adopted (see text). The Bliniz projectile launched by the Cougar is over the threshold value.

Fig. 7 shows the kinetic energy of different projectiles. The kinetic energy of a 'standard' baseball 53 J [25] is taken as a threshold value. For the Cougar the kinetic energy is over the threshold value. From these data it seems evident that one should not aim at somebody's face. For this reason ballistic consistency and accuracy of fire are important.

From Fig. 8 it is apparent that for the Cougar the result for the kinetic energy density is better and below the threshold value of 6 J/cm², while for the FN303 the energy density is above this value. The threshold value has been suggested by Sellier and Kneubuehl [26]. Skin can perforate if the energy density is larger than 10 J/cm². The cornea can be perforated at a value of 6 J/cm² [26], but unfortunately also lower values can cause permanent injuries to the eye.

Fig. 9 shows the depth of cavities in plasticine for different projectiles. As threshold value 44 mm is adopted, which is taken from body armour tests [27]. While the Bliniz projectile launched by a Cougar weapon gives a rather high kinetic energy (over the threshold), its results for both energy density and depth of cavity in clay are well below threshold values. For FN303 it is the other way round, the kinetic energy is below the threshold value, and for both energy density and depth of cavity in plasticine, results are over the threshold values.

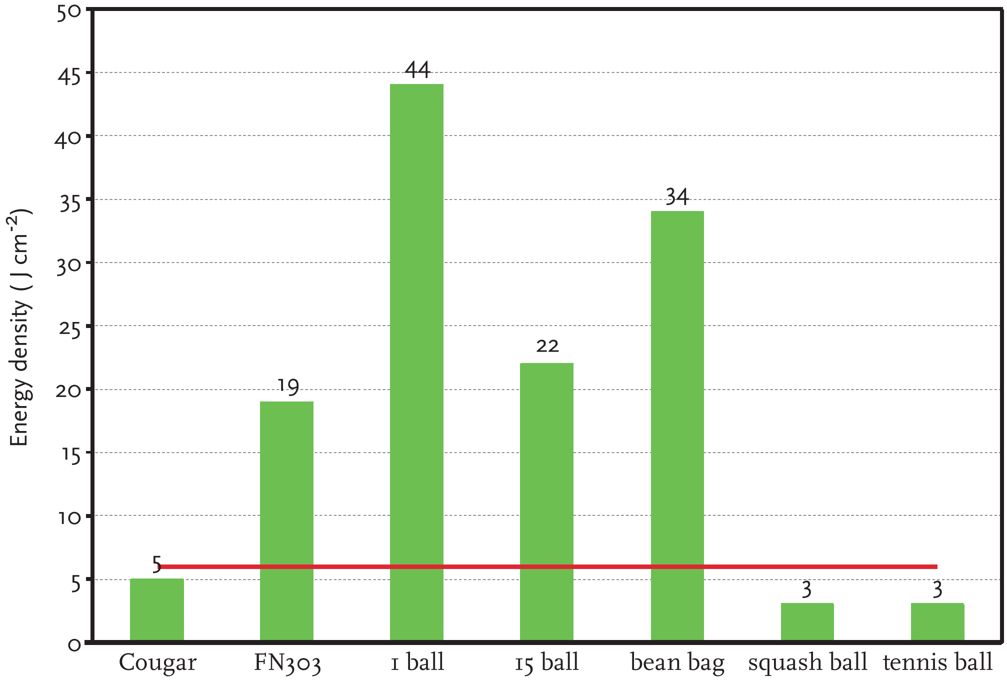

Figure 8. Kinetic energy densities of different projectiles. The red line represents the threshold value (6 J/cm², *see text). Evidently, the kinetic energy density of the FN303 projectile is over the threshold value.*

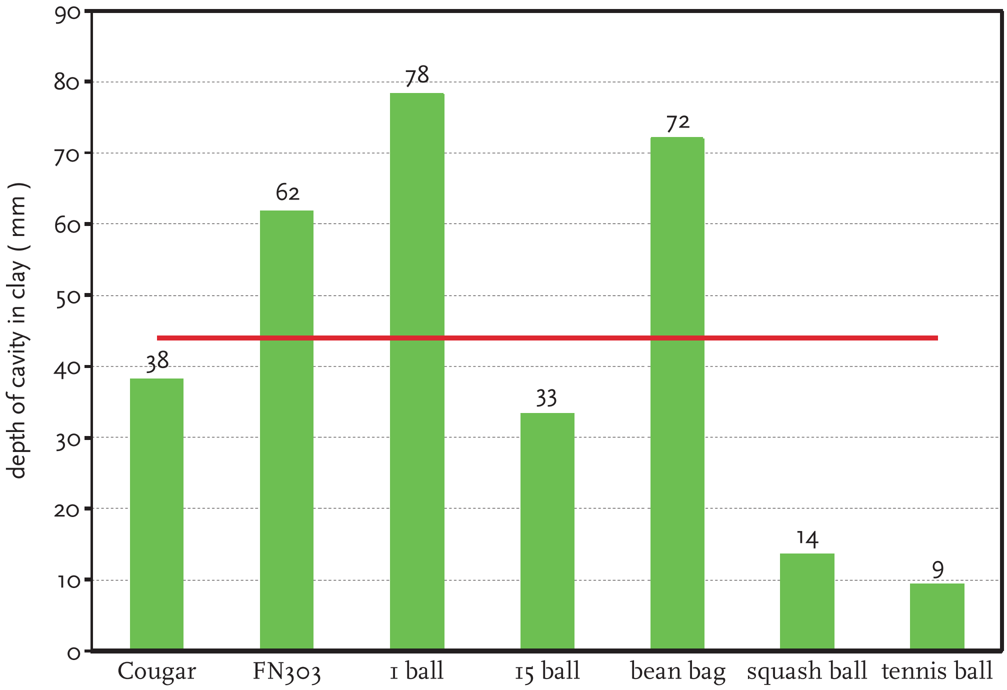

Figure 9. Depth of cavities in plasticine for different projectiles. The red line represents the threshold value (44 mm, *see text). Evidently, the cavity due to the FN303 projectile is over the threshold value.*

However, we do not know how much energy is transferred to the target and which stresses occur caused by impact. An indication of energy transfer to the human body is obtained by measuring the energy transfer to a ballistic pendulum. From the experimental results it is evident that the Bliniz (Cougar) projectile transfers 4-8% of its kinetic energy to the pendulum, while the FN303 transfers only 0.1-0.5%. This implies that for the Bliniz projectile less energy is lost to deformation, rebound, heat and other possible loss factors than for the FN303. This may be attributed to the different nature of the projectiles. The FN303 projectile breaks upon impact and the Bliniz projectile only deforms. Also, the difference in mass of the projectiles can be expected to be important [24].

Discussion and summary

In the last decade, the interest in non-lethal weapons has increased considerably, see e.g. [28-32]. This is a consequence from both progress in non-lethal technology and growing interest from both military forces and civil police for more sophisticated and proportional responses to violence. At the moment there are *no* weapons that are 100% non-lethal. However, different classes of non-lethal or less lethal weapons are all intended to inflict as little physical damage as possible while still reliably subduing or incapacitating a person. The same is true for kinetic non-lethal weapons. These goals stand in contrast to traditional weapons development, which focuses on increasing the lethality of weapons. Fortunately, even now lethal effects and permanent injury due to these weapons is *much less likely* than with their conventional lethal counterparts.

New technologies for 'non-lethal' weapons require training of expert users, also because it further minimises harm. The same is true for knowledge of and development for medical treatments for people hit by a kinetic projectile. Also worth mentioning here are a few other important factors. One is the *shooting distance* in relation to safety of both the target and user of the weapon. Also important is the *accuracy* of the weapon. For some weapons a hit on a 'wrong' area (for instance the face) will result in permanent injury or lethality. Moreover, safety of personnel may require use of a lethal weapon. Also, when introducing non-lethal weapons one should be aware that criticism exists about the (ab)use of non-lethal weapons in the recent past. It is argued that these weapons can augment rather than replace lethal technology, see e.g. [33,34]. Like with conventional weapons, one would not like them to be available for the wrong people. So, governments and international communities should take measures to prevent proliferation.

In this orienting study experimental methods and physical parameters of so-called kinetic non-lethal weapons are investigated and reviewed. Some experiments were discussed to show the challenges and possibilities of this developing field. Two commercially available weapon systems, FN303 and Bliniz/Cougar, have been investigated and their impacts have been compared to tennis, squash, rubber balls and beanbags. Both systems demonstrate interesting kinetic weapon concepts. Though the kinetic energy and the kinetic energy density of projectiles are important parameters, we showed that they are not sufficient to classify the lethality of a weapon system. Apparently, there are other factors that co-determine the lethality. The reason why (kinetic) energy and damage are not always correlated is that damage is not due to energy transfer, but to too much stress in tissue. We think computer simulations are useful to augment our understanding of this impact process. However, this requires adequate physical and biomechanical input parameters. In case of kinetic non-lethal weapons the role of the skin tissue cannot be neglected. In this paper a number of useful figures have been collected which will serve as a starting point for future work in this field. For this research we intend to use the finite element program AUTODYN.

Non-lethal weapons are a relatively new topic in the field of combat systems research. For non-lethal weapon systems different promising evaluation methods have been investigated. However, these methods require improvements and also new methods may be available in the future. At present, there are few consensuses in this field. This multi-disciplinary subject requires independent research by non-commercial institutes.

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