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ORIGINAL ARTICLE

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On the physics of momentum in ballistics: can the human body be displaced or knocked down by a small arms projectile?

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Abstract Shooting incidents are often portrayed as resulting in a sometimes violent backwards displacement of the victim. This opinion is also not infrequently held by expert witnesses. The physical force responsible for this would be momentum (mass × velocity). The physics of momentum in ballistic injury is explained in detail. The maximum momentum transferred from different small arms projectiles including large calibre rifles and a 12-gauge shotgun only results in a backwards motion of a 80 kg target body of 0.01–0.18 m/s, which is negligible compared to the velocity of a pedestrian (1–2 m/s). Furthermore, counterbalance is constantly maintained by neurophysiological reflexes. So the effect of the momentum transferred from the missile is virtually zero and there is no backwards motion of the person shot. Empirical evidence verifying these calculations can be obtained from hunting big game, from human gunshot victims and from a video documentary demonstrating the lack of any backwards motion of a person wearing body armour after hits from a centre fire rifle. So the alleged backwards hurling of a person shot is nothing but a myth which should be refuted not only because it is incorrect but also because it can result in miscarriages of justice.

Key words Gunshot wounds · Momentum · Physics · Wound ballistics

Introduction

In addition to the tissue disruption caused by a projectile, the effect of a hit can also be discussed in terms of physics: it can be crucial to know if a bullet or shotgun pellets necessarily knocked a person backwards or if this person was able to retain the standing position. For example, a man with a fatal gunshot wound of the chest was found lying on top of his shotgun. In the report for the court, it was one expert's opinion that suicide was unlikely because the man should have been hurled backwards by the impact of the shot pellets (Provincial Court Oldenburg, 126 Js 53172/93).

Most text-books of Legal or Forensic Medicine (e.g. Gonzales et al. 1954; Smith and Fiddes 1955; Tedeschi et al. 1977; Knight 1991) do not comment on this topic. It is the intention of this paper to evaluate the quantity of momentum transferred from a missile and to examine it's effect on the human body, thereby re-examining the alleged backwards displacement of persons shot. This can be accomplished by rather simple considerations and observations.

The physics of momentum

The linear motion of any object can be described by its linear momentum p that is given as the product of the mass m and the velocity v of the object:

$$p = m \cdot v \quad (1)$$

If two objects collide, the motion can be partially or totally transferred from one object to the other. According to the linear momentum theorem, the total linear momentum of a system of two objects remains constant and therefore has the same total momentum before and after the collision.

This principle is also valid in the case of a bullet hitting a person. If the person does not move before being hit, the momentum of the bullet before the hit (p_1) is equal to the sum of the momentum of the body after the hit (p_2) and the momentum of the exiting bullet (p_3), i.e.:

p_1 (bullet momentum) = p_2 (momentum of body) + p_3 (momentum of the exiting bullet)

The highest transfer of motion to the body results when the bullet remains in the body (or in a ballistic vest worn

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by the person) because in this case $p_3 = 0$. According to Eq. (1) and the linear momentum theorem, the following equation is valid in this "worst case" scenario:

$$m_1 \cdot v_1 = (m_1 + m_2) \cdot v_2 \quad (2)$$

where m_1 is the mass of the bullet and v_1 it's velocity before the impact, m_2 the mass of the body and v_2 the joint velocity of bullet and body after impact. Because $m_1 << m_2$, $m_2 \approx m_1 + m_2$ is valid and v_2 can be expressed as:

$$v_2 = \frac{m_1}{m_2} \cdot v_1 \quad (3)$$

So the "throwback" velocity or the pendulum effect of a person shot (v_2) can be calculated from the mass of the bullet divided by the mass of the target, multiplied by the impact velocity of the bullet.

Table 1 shows the ballistic parameters of seven different projectiles from small arms including the muzzle momentum of the bullet and the "throwback" or recoil velocity of a 80 kg body (no exit). The transfer of motion results in a backwards velocity v_b (= v_2) of 0.01–0.18 m/s. It should be obvious that this velocity is negligible compared to, for example, the speed of a person walking (1–2 m/s). Furthermore, the human body does not stand passively on frictionless roller skates, which is the assumption when calculating the "throwback" velocity according to the linear momentum theorem, but either stands with both feet on the solid ground or is already in motion. If the person shot is moving, this pre-existing momentum by far exceeds the additional momentum from the missile. If the target body has no momentum of it's own, the small amount of momentum transferred from the bullet will have no noticeable effect because balance is instinctively maintained by a physiological control circuit, which constantly counterbalances the body against disturbing factors such as a slight push or a bullet's impact. In real situations, it is obvious that the momentum transferred from the bullet will not be strictly linear but will usually be effective as a combination of linear, rotational and vertical motion of the body with each component obtaining a portion of the total momentum.

The physics of a bullet's "push" can also be understood by a comparison of the physical forces acting on the person shooting and on the person receiving the hit, i.e. *actio = reactio*. If the person shooting is not driven back significantly, how can the person sustaining the wound be driven back? The amount of recoil momentum of the firearm is even higher than the momentum of the bullet at the muzzle because hot powder gases follow the bullet from the muzzle with high velocity, thus increasing the recoil momentum of the firearm. Therefore, the momentum transferred to the target cannot equal the recoil of the firearm. But the two forces are effective in opposite directions. When a person commits suicide while firmly holding the gun, which is the common way of shooting, the total momentum of the body/weapon system consequently tends towards zero. This demonstrates, apart from the negligible momentum transferred, the additional misapprehension behind the idea that an ordinary suicidal gunshot could result in displacement of the whole person. Furthermore, there is no difference if the momentum is in the form of a solid projectile (bullet) or in the form of multiple missiles (shot pellets, fragments from explosive devices).

Table 1 The mass of the bullet (m) and the muzzle velocity (v_0) were taken from various manufacturer's specificities and from Sellier and Kneubuehl (1994) in cases of non-shotgun firearms. The mass of the pellets from a 12/70 shotgun is approximately 30 g depending on manufacturer and pellet size. The velocity of pellets varies even in a single gunshot. The velocity of 400 m/s used for calculation corresponds approximately to the medium velocity of recordings by Nennstiel and Grooß (1980) and to manufacturer's specificities

Cartridge	m [g]	v_0 [m/s]	E_0 [J]	p [N·s]	v_b [m/s]
.22 lr	2.5	330	140	0.8	0.01
9 × 19 mm Luger	8.0	350	490	2.8	0.035
.45 ACP	14.9	260	505	3.9	0.049
.44 Rem. Mag.	15.6	440	1510	6.9	0.086
.308 Winchester	9.5	830	3270	7.9	0.099
.375 H&H Magnum	17.5	835	6100	14.6	0.18
12/70 shotgun	~ 30	~ 400	~ 2400	~ 12	~ 0.15

E_0: muzzle energy
p: momentum of the missile
v_b: backwards velocity of a 80 kg body

Empirical evidence

Every hunter knows that big game such as deer or wild boar, when shot with an appropriate centre fire rifle, react differently depending on the species and the area of the hit – but it definitely is never actively thrown anywhere or knocked down as if by an invisible fist. If it moves at all, it is always an impulsive reaction of the animal to the gunshot wound but not a physical force such as momentum acting from outside. Abundant empirical evidence is also available from human gunshot victims. There are numerous reports (e.g. Tedeschi et al. 1977) from persons who at first did not even realize they had been struck by a bullet. Others only noticed a local blow which did not affect their momentary activity.

For those who do not trust "fisherman's tall stories" or theoretical physical considerations, the video documentary "Deadly effects: wound ballistics" (Jason 1987) is recommended. While wearing body armour with ceramic or steel plates, the author is shown to be shot twice from close range with a 9.5 g, 7.62 mm NATO rifle bullet (= .308 Winchester, see Table 1). He is not moved backwards perceptibly, not even while balancing on one foot. Also, everyone who has ever fired experimental gunshots into blocks of gelatine or soap knows that these blocks, which have far less mass than a human body, show only small linear motions. What more can be said? So once and for all: no momentum-induced translocation of a person receiving a hit from a small arm takes place.

A myth easy to disprove but hard to destroy

So-called experts again and again tell Judges that a bullet will knock down a man or throw him backwards. If this statement is not refuted in the courtroom, the person accused of shooting someone may suffer a miscarriage of justice. But why is it that the unequivocal evidence presented is ignored so many times? The numerous misleading depictions of shootings in entertainment films including people being hurled backwards through a door may have contributed to the longevity of this misconception (Fackler 1992). But the real reason is probably that wound ballistics is centred on the missile-tissue interaction (Fackler 1988) and is therefore based on two large disciplines: medicine and physics. So a medical expert dealing with gunshot wounds should try to acquire some knowledge of physics. If this is not achieved, fundamental laws of physics will be neglected and the reconstruction of a shooting will be unsuccessful or simply incorrect, which can have dangerous implications. Simple scientific method is enough to reveal that the alleged backwards hurling of a person shot is just another myth in wound ballistics – a myth that seems to be difficult to eliminate even from the minds of some people involved in the investigation of gunshot wounds.

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