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FÜLÖP, PÉTER

„Body physics" – Innovative options for supporting forensic medical expert practice in Hungary[1]

Introduction

It is a frequently stated assertion that intelligent, cultured, dialogue-based debate advances the parties involved. In everyday life, however, conflict resolution sometimes deviates from this ideal scenario. It happens that the unleashing of emotions overrides the rational approach, and the process leads to physical violence, the consequences of which are only weighed in court. The characteristic of such situations is that the bodies of the persons involved are subjected to various mechanical forces, the objective examination of which using natural scientific tools may be essential for establishing responsibility.[2]

The study places particular emphasis on demonstrating the interdisciplinary possibilities inherent in collaboration between physics and medicine. At the boundary of these two professional areas, a new approach emerges, to which the term "body physics" may provide a more precise framework. In this context, the concepts of force and energy appear not merely as textbook definitions, but also from a unique perspective, offering the opportunity to better understand the relationship between the human body and physics from the perspective of assaults.

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[1] This study is the English version of a presentation delivered at the conference Research and Innovation in Law Enforcement, Pécs

[2] Fülöp, P.: Brutális fizika másképp – Fizikusok az igazság nyomában [Brutal Physics Revisited – Physicists in the Pursuit of Truth]. Magyar Rendészet, Issue 2019/2–3. 67–87. o.

„Body physics"

If a peaceful resolution of an imaginary dispute does not occur and an individual uses, for example, a knife or a snow shovel, such actions often result in criminal proceedings. In such cases, with expert involvement, it may be necessary to uncover the criminally relevant details of past events to clarify the facts. From the authority's side, when compiling the appointment order or decision, the following questions may arise - without claiming completeness:

- What could have been the mechanism of injury formation?
- What trajectory could the thrown object have followed?
- What magnitude of force could it have experienced?
- What could have been the applied force during stabbing?
- What injury did it cause, could it have caused, if...?

Practising police officers, prosecutors, and judges may subsequently face the question of whether to appoint a forensic medical expert or a forensic physicist for these matters. In expert practice, the appropriate answer is "both" rather than "either".

It is a commonplace thought that wherever we look, physics surrounds us, but we can hardly name an area where it does not appear. It explains most of the phenomena occurring in our material world and is also one of the engines of technological development. It is also encountered in medicine; medical biophysics deals with phenomena related to the human body as a living organism and the physical foundations of various life processes within the body, one of its special branches being biomechanics. The criminalistic application of physics in Hungary is an extremely diverse field[3],

[3] Fülöp, P. – Varsányi, I.: Az igazságügyi fizikus szakértői terület jelen és jövője [The Present and Future of the Field of Forensic Physics Expertise]. In: Kosztya, S. J. et al. (eds.): Forenzikus füzetek: A Nemzeti Szakértői és Kutató Központ jelene és jövőképe II. Budapest, 2024. 63–72. o.

and, based on the above line of thought, we find several points of connection among biophysics, biomechanics, and forensic medical expert practice. These may include, for example, falls from heights, various motions (e.g., projectile motion), or even thermal phenomena (e.g., hypothermia).

Based on the methodological letter on forensic medical opinion on bodily injuries and health damage, which is being prepared and will appear soon, determining the nature, magnitude, and direction of the effects of force is fundamentally a matter of medical expert competence. Starting purely from the characteristics of the injury, medical experts can, based on their professional knowledge and experience, estimate the minimum force that could have contributed to the development of the given alteration. In practice, it is customary to distinguish between small, medium and large forces, as well as force effects exceeding human force exertion. As a physics expert, my goal is always to examine events from multiple perspectives using the methods of physics from the available information, revealing the most objective reality possible. Based on the examination results, the aim is to support law enforcement's work by providing objective findings. During the opinion-giving process — alongside impartiality and neutrality, refraining from the legal qualification of cases — from an expert perspective, it often arises whether the end users of the expert opinion were actually curious about the magnitude of the actual force acting on the body surface or, in given cases, the force exerted by a person? This uncertainty may stem from the fact that natural scientific and legal concepts can be interpreted differently and operate within different logical frameworks. Nevertheless, it must be kept in mind and striven for that the expert opinion is substantively usable in the given procedure. To illustrate the importance of an interdisciplinary approach, the dual nature of light is often cited as an illustrative example: one of the great questions of physics at the end of the 19th century and the beginning of the 20th century was whether light was wave-like or particle-like.[4] Quantum mechanics, which describes the phenomena of the microworld, then pointed out that the question itself was wrong. Light is both a wave and a particle, just as a rotating cylinder appears rectangular from the side view and circular from the top view. We see the same object, just from a different perspective. Based on this consideration, the analysis of injuries on the human body may also be justified from multiple viewpoints, and, if necessary, the involvement of co-experts (e.g., forensic physicists, engineers, forensic mark and firearms experts) may be appropriate[5].

The international literature includes the work of Lawrence Davis, *"Body Physics: Motion to Metabolism,"* which demonstrates the movement, metabolic processes, and biomechanical functioning of the human body through the application of the laws of physics—primarily for educational purposes.[6] In this study, the term "body physics" is reinterpreted by experts. In this context, "body physics" denotes an interdisciplinary approach that combines physics methods with forensic medical expert practice. This special field contributes to a more accurate description of the forces acting on the body, interactions, and their consequences, providing an opportunity specifically for the interpretation, modelling, and objective explanation of injuries sustained during assaults.

Physical foundations of force effects acting on the human body surface

According to the constructivist pedagogical model of learning, naive theories and misconceptions hinder the acquisition and deepening of natural

[4] Nagy, K.: Kvantummechanika [Quantum Mechanics]. Nemzeti Tankönyvkiadó. Budapest, 1978. 34–37. o.
[5] Lontai, M. – Kosztya, S. J.: Az intézményi szakértés kihívásai a technológiai fejlődés tükrében [The Challenges of Institutional Expert Practice in the Context of Technological Development]. Ügyészek Lapja, Issue 2023/5–6. 78–80. o.
[6] Davis, L.: Body Physics: Motion to Metabolism [Testfizika: Mozgástól az anyagcseréig]. Open Oregon Educational Resources. 2018.
Source: https://openoregon.pressbooks.pub/bodyphysics/
Accessed: 10.07.2025

scientific knowledge.[7] One of the best examples of this in physics is the nearly 2000-year-old prevailing view, i.e., the Aristotelian worldview, according to which, using our modern concepts, force is necessary to maintain motion as a process.[8] This model was based on everyday experiences and persisted until Newton's work, until the birth of classical mechanics. Everyone had prior knowledge about force before sitting in school desks and hearing about Newton's laws in physics lessons. This knowledge may later be so strongly opposed to what was learned that the so-called conceptual change does not occur, and the acceptance of new knowledge becomes impossible.[9]

The misunderstanding of the concept of force presents a problem not only from a pedagogical perspective but also in legal and forensic professional fields. The difference between the everyday and physically exact interpretation of force can lead to serious misunderstandings, for example, in official procedures. Whether we ask a small child or an adult about this, they will certainly have some knowledge and experience related to force. For many of us, the strength of our muscles comes to mind first, while for others, the "Force" from Star Wars, which permeates the entire Empire, comes to mind. With force, we move bodies, set them in motion. However, it is well known that bodies move without human intervention or muscle force.

[7]Nagy-Czirok, L.: Tévképzetek és fogalmi váltások – Hogyan változik a tanulók természettudományos gondolkodása [Misconceptions and Conceptual Change – How Students' Scientific Thinking Changes]. *Új Pedagógiai Szemle*, Issue 2018/3–4. 47–50. o.
Source: https://folyoiratok.oh.gov.hu/uj-pedagogiai-szemle/tevkepzetek-es-fogalmi-valtasok-hogyan-valtozik-a-tanulok-termeszettudomanyos
Accessed: 10.07.2025

[8]Simonyi, K.: A fizika kultúrtörténete a kezdetektől a huszadik század végéig [A Cultural History of Physics from the Beginnings to the End of the Twentieth Century]. Akadémiai Kiadó. Budapest, 2021. 86–87. o.

[9]Kiss, Cs. (n.d.): A konstruktivista tanuláselmélet bemutatása a mechanika példáján keresztül [Presentation of Constructivist Learning Theory through the Example of Mechanics].
Source: http://sac.web.elte.hu/sulaj/didaktika/konstr/modszer.htm
Accessed: 10.07.2025

In physics, force is nothing other than the mutual effect of bodies (or fields) on each other, which we experience in the form of changes in motion and/or shape. In the language of mathematics, force is the time derivative of momentum (quantity of motion) with respect to time, which is the basic equation of mechanics[10]:

$$\vec{F} = \dot{\vec{p}} = \frac{d\vec{p}}{dt} = m \cdot \frac{d\vec{v}}{dt} = m \cdot \vec{a}$$

The measure of force effect is the force F, which has magnitude and direction (point of application and line of action), thus it is a vector quantity. The unit of force is the newton (N), and it follows from the above that 1 N is the force effect required to accelerate a body of mass 1 kg by 1 m/s^2 to a velocity of 1 m/s (3.6 km/h) in 1 second. Expressed somewhat more comprehensibly, the magnitude of force is given by the product of the change in speed per unit time, i.e., acceleration, and the inertial mass of the body to be accelerated.

The fundamental difference between the Aristotelian conception of motion and Newtonian mechanics is that force can accelerate (decelerate) bodies, can change their shape, and can exert a rotational effect, as expressed by the torque detailed later.

Forces occur in many forms in nature. Force effects can arise through direct contact, which we call surface forces distributed over a surface, and also through volume forces acting on the entire mass without contact. Surface forces can be further grouped into those acting along a surface or line and those acting at a point[11]. The effects of other bodies cause so-called external forces, while internal forces are the effects of one part of a body on another. External forces also have two types: one is an active force, such

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[10] Budó, Á.: Kísérleti fizika I [Experimental Physics I]. Tankönyvkiadó. Budapest, 1986. 56–58. o.

[11] Kocsis, L. – Kocsis, L.-né: Mechanikai alapok [Fundamentals of Mechanics]. In: Kocsis, L. – Kiss, G. – Illyés, Á. (eds.): Mozgásszervek biomechanikája. Terc Kft. Budapest, 2007. 20. o.

as the weight of bodies; the other is a passive force, or reaction force, which arises on support surfaces, such as a compressive force.[12] If we have found a group of motions that similar mathematical relationships can describe, then we have created a force law (e.g., a linear force law, a gravitational force law, a friction force law, etc.). The force law is not characteristic of the body exerting the force effect itself, but of the properties and capabilities of the bodies participating in the interaction.

Strength as a conditional ability of the individual

In sports science, according to the training theory approach, strength is one of the basic conditional abilities. Muscle strength is such an internal force when muscle contraction occurs as a result of a stimulus. During contraction, the muscle itself performs work, so a person — through the active force exertion of their musculature — is capable of overcoming external resistances. Muscle movement is a series of chemical reactions taking place in muscle cells, and the muscle fibres' contraction thus formed brings the joint between the origin and insertion of the muscle into motion, which manifests as rotation, for example, when lifting a weight held in our hand. The movement of joints can be described by torque based on the following relationship:

$\vec{M} = \vec{r} \times \vec{F}$, from which the magnitude of torque is
$\left|\vec{M}\right| = \pm F \cdot r \cdot sin\, sin\, \varphi\ = F \cdot k$, where F is the (muscle) force, k is the leverage, r is the distance between the tendon attachment site and the pivot point.[13]

[12] (n.d.): Biomecha jegyzet 2012 – klasszikus mechanika [Biomechanics Notes 2012 – Classical Mechanics].
Source: https://vik.wiki/F%C3%A1jl:Biomecha_jegyzet_2012_klasszikus_mechanika.pdf
Accessed: 10.07.2025

[13] Ángyán, L.: Az emberi test mozgástana [Kinesiology of the Human Body]. Motio Kiadó. Pécs, 2005. 50–51. o.

Muscle activity also significantly affects movement speed. From the interactions of basic abilities such as strength, speed, and endurance, we also distinguish special abilities according to the type of muscle force exerted:[14]

- maximum strength,
- rapid reaction force,
- stamina.

The theoretically achievable greatest, so-called absolute strength, may be 30% greater in untrained individuals than what we are voluntarily capable of exerting maximally. The remaining 30-35% of absolute performance is under inhibition under everyday circumstances. This autonomous protected reserve can be depleted by emotions and stress, ultimately leading to complete exhaustion.[15] The magnitude of maximum force depends on the cross-section of muscle fibres and the number of simultaneously activated motor units, i.e., the cooperative ability of individual muscle fibres. Generally speaking, maximum force ranges from 23-42 $\frac{N}{cm^2}$ when broken down to the cross-section of human musculature.[16] Rapid reaction force involves short-term, vigorous muscle tension, during which the muscle overcomes resistance corresponding to approximately 30-40% of maximum force with relatively high-speed contraction.[17] This ability plays a role in the majority of assaults, the magnitude of which depends on the degree of intra- and intermuscular coordination.

Based on the above, it is clear that applied force and resulting force are distinct concepts that do not necessarily correspond. In many cases, there

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[14] Pavlik, G.: Élettan – Sportélettan [Physiology – Sports Physiology]. Medicina Könyvkiadó. Budapest, 2011. 238. o.

[15] Barton, J.: Biomechanika [Biomechanics]. Nemzeti Tankönyvkiadó. Budapest, 1983. 110–111. o.

[16] Pavlik, G.: i.m. 240. o.

[17] Petridis, L. (2015): A sportteljesítmény fizikai összetevőinek diagnosztikája [Diagnostics of the Physical Components of Sports Performance]. Campus Kiadó. Debrecen, 2015. 32. o.

is no causal relationship between the exerted (muscle) force and the resulting injury, or between the actual force acting on the body surface and the injury. As a result, conclusions cannot be drawn about the perpetrator's motivation or intention. Therefore, in expert appointments, it is necessary to ask precise questions that take professional aspects into account so that the expert can provide the most satisfactory answer to establish the facts.

Deformations and stress

According to the definition in the previous point, the effect of force can also manifest as deformation. Based on one of our most fundamental everyday experiences, if we compress, for example, a ball, its shape changes. In physics, we interpret the pressure on the ball as a compressive force acting perpendicularly to the unit surface, the magnitude of which can be given by the following relationship:

$$p = \frac{F}{A}$$

This definition is somewhat incomplete from a physical perspective, since pressure is a quantity not related to direction, unlike vectorial compressive force. Let us take a solid body on which an external force acts! Under this loading force, the body deforms and internal stress develops. The resulting deformations can be traced back to a few well-defined types[18]:

- tension,
- compression,
- shearing,
- bending,
- torsion.

[18] Kocsis, L. – Kocsis, L.-né (2007): i.m. 43–47. o.

Materials often differ in their ability to withstand tensile or compressive loads. In the case of homogeneous, isotropic bodies and small deforming forces, the deformation is directly proportional to the load and inversely proportional to the cross-section of the body. The proportionality factor is the elasticity coefficient or Young's modulus characteristic of the elasticity and material quality of the given body. In the case of elongation, it takes the following form[19]:

$$\frac{F_{tensile}}{A} \cdot l \sim \Delta l$$
$$\frac{F_{tensile}}{A} \sim \frac{\Delta l}{l}$$
$$\sigma_{tensile} = E \cdot \varepsilon$$

This relationship is the material law of an elastic body subjected to simple stress, Hooke's law. Here we call the ratio $\frac{F}{A}$ stress (force acting over an area) more specifically tensile stress, and E denotes Young's modulus and ε called strain deformation (i.e., relative length change).

Biomechanical applications of force in forensic medical expert practice

When we discuss deformations in relation to the human body, most people probably first think of bone injuries. Fractures are the most vivid examples of when the structure of a material permanently changes under the effect of external force. Bone is actually a material with viscoelastic properties (more precisely, an anisotropic, heterogeneous, non-linear, rheologically complex one). Viscoelastic behaviour means that they simultaneously show properties characteristic of elastic materials and viscous liquids.[20]

[19] Budó, Á. (1986): i.m. 209–221. o.
[20] Kocsis, L. – Kocsis, L.-né (2007): i.m. 59–62

One of the main characteristics of these materials is that under the effect of loading, the material response depends, among other things, on the elapsed time and the loading rate. In the case of short-duration, high loading, the material's viscous behaviour dominates, whereas in the case of long-duration, low loading, elastic behaviour dominates. The relationship between stress and relative elongation is not linear, as in the case of Hooke's law, but both are functions of time. From this, behaviour proportional to the deformation rate, relaxation under stress ($\frac{d\varepsilon}{dt} = 0$), as well as creep ($\frac{d\sigma}{dt} = 0$) can also be observed.[21]

The examination of bone properties is similar to that of the structural examination of metals, ceramics, and plastics. Under different stress conditions, the load-bearing capacity of bones and the forces required to fracture them can be measured using specialised equipment. From the measurements shown in the educational film *"Secrets of Bones"*, we can see that a deer's femur can withstand a transverse force of approximately 4500 N and a longitudinal force of approximately 17000 N. The strength of human bones also depends on the direction of loading (anisotropy). If we know the external diameter and wall thickness of a given bone, e.g., the tibia, then, using the compressive strength data from tables and the previously discussed relationship, we can estimate the maximum static compressive force (uniform loading) it can withstand without fracture. According to my calculations, not detailed here, it could withstand a load of up to 55000 N (55kN), i.e., the weight of a body with a mass of approximately 5.5 tonnes. The question arises: what magnitude of effects could we say in forensic medical practice constitutes small, medium, or large force effects? Can forces of a few tens or hundreds of N also create serious injuries on the human body?

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[21] Tamás, P. – Bojtos, A. – Décsei, A. – Paróczi, A. – Fekete, R. T. (n.d.): Végeselem módszerek, 2.4. Anyagmodellek létrehozása [Finite Element Methods, 2.4 Creation of Material Models].
Source: https://mogi.bme.hu/TAMOP/vegeselem_modszerek/math-ch02.html
Accessed: 10.07.2025

Compressive force on the skin can typically be discussed in terms of injuries caused by tools with points and edges. The magnitude of forces transmitted by knife stabs depends on the thickness and elastic properties of clothing items worn by the victim, human factors such as the mechanical properties of the skin, stabbing technique, and the morphological and geometric characteristics of the tool.[22, 23, 24] In addition to measuring the width, length, and possibly thickness of the knife blade, determining the opening angle and radius of curvature of the point is of paramount importance. These parameters decisively influence the magnitude of the penetration force through the skin, which can be measured with a universal material testing device under static stress, or even with a digital scale in the absence of such equipment, but numerical methods are also applied.[25] Penetration force is the minimum force required with which the given material (human skin and/or clothing) can be pierced with the available tool using uniform compressive force. Test stabs can be performed on young pig skin with elastic properties similar to those of human skin that has not been previously frozen, or on ballistic gel[26]. If we know the penetration depth of the knife (the length of the stab channel), then from this and the penetration force, we can derive the magnitude of (penetration) energy suitable for predicting injury potential, discussed later.[27] Generally, for knives, the smaller

[22] Hoguea, M. – Fairgrieve, S. I. – Lievers, W. B. (2020): Stabbing angle alters peak force and work during sharp force trauma of porcine ribs. Forensic Science International, 314. 110373

[23] Ankersen, J.: Quantifying the forces in stabbing incidents [Quantifying the Forces in Stabbing Incidents]. University of Glasgow. 1999. 18–34. o.

[24] Horsfall, I. – Watson, C. – Champion, S. – Prosser, P. – Ringrose, T.: The effect of knife handle shape on stabbing performance. Applied Ergonomics, Issue 2005/36. 505–511. o.

[25] Ní Annaidh, A. – Cassidy, M. – Curtis, M. – Destrade, M. – Gilchrist, M. D.: A combined experimental and numerical study of stab-penetration forces. Forensic Science International, Issue 2013/233. 7–13. o.

[26] Terefe, T. O. – Chawla, A. – Datla, N. V.: Low-velocity nail penetration response of muscle tissue and gelatin. Forensic Science International, Issue 2024/361. 112082

[27] Bolliger, S. A. – Kneubuehl, B. P. – Thali, M. J. – Eggert, S. – Siegenthaler, L. (2016): Stabbing energy and force required for pocket-knives to pierce ribs. Forensic Science, Medicine, Pathology, Issue 2016/4. 394–398. o.

the opening angle (and radius of curvature) of the blade point, the smaller the penetration force, and the smaller the penetration angle, the larger the penetration force. Based on the measurement results of various studies, it can be said that in the case of tools with points and edges, the penetration force is typically 30-300 N.[28] Experiments have also established that the measured values can be categorised analogously to forensic medical terminology, i.e., in the case of stabs, penetration force below 50 N can be classified among effects with low-force impacts, forces between 50-150 N among medium forces, while force above 150 N among effects involving high-force impacts.[29]

An interesting question for football fans, important from a health perspective for sports specialists, and also a professional question in litigation, is: how hard can a ball be hit?[30] During a break between classes at an educational institution, a student was hit from behind by a misdirected football under disputed circumstances. The purpose of the expert appointment was to explore the relationship between the presumed health damage and the magnitude of the blow to the head, for which the district court could not provide objective data. On the one hand, this made the task difficult. It fell to the physics expert to support the medical expert's work by providing data on distance and velocity. On the other hand, this information does not provide real help from a professional perspective. Velocity alone does not reveal much about the dynamics of motion, so instead the analysis focused on determining the change in speed over time, i.e., acceleration, and the force exerted on the head by the ball, which is proportional to this.

[28] Heckmann, V. – Engum, V. – Simon, G. – Poór, V. S. – Tóth, D. – Molnár, T. F.: Piercing the surface: A mechanical analysis of stabbing with household tools. Journal of Forensic Sciences, Issue 2023/4. 1218–1227. o.

[29] Nolan, G. – Hainsworth, S. V. – Rutty, G. N.: Forces generated in stabbing attacks: an evaluation of the utility of the mild, moderate and severe scale. International Journal of Legal Medicine, Issue 2018/1. 229–236. o.

[30] Nauheim, R. S. – Bayly, P. V. – Standeven, J. – Neubauer, J. S. – Lewis, L. M. – Genin, G. M.: Linear and angular head accelerations during heading of a soccer ball. Medicine and Science in Sports and Exercise, Issue 2003/8. 1406–1412. o.

During a collision, the ball undergoes elastic deformation. At the moment of impact, the head becomes flattened (to an extent depending on the kicking force and the pressure prevailing in the ball). If we had a recording of the moment of collision, from which we could measure the extent of the ball's flattening and the path length of its deformation, then the force could also be estimated from the pressure exerted on the head.

In the absence of such a photograph, an alternative approach was chosen to address the question: estimating the collision time and the magnitude of impact velocity. After impact, the ball regains its original shape. We call this process an elastic collision, during which the ball bounces back from the head with the same speed with which it collided. From this, the velocity change of the football can be determined, which is twice the impact velocity ($\Delta v = 2v$). The force exerted by the ball on the head during collision accelerates the head, the magnitude of which, according to calculations not detailed here, is approximately 600-1100 N based on the second law of Newton. Such a force effect could have accelerated the child's head with an acceleration of up to 19g, a value that barely falls short of the magnitude of blows measured on boxers' heads that are equivalent to a K.O.[31]

Based on the above example, there is very rarely an opportunity to calculate the magnitude of forces occurring during interactions between everyday objects and the human body without knowledge of the deformation path length and collision time. In these cases, we can indirectly determine the impact energy, which also refers to the force exerted by the perpetrator's limb muscles, which we can then compare with the characteristic impact energy of other objects and their physical effects. Impact energy can be approximated as kinetic energy and cannot be measured directly; for its

[31] Horváth, G. – Juhász, A. – Tasnádi, P.: Mindennapok fizikája [Physics of Everyday Life]. ELTE TTK Továbbképzési Csoport, Budapest, 1989. 157–162. o.

calculation, it suffices to specify the most important factor in the interaction, the impact speed of the colliding body, and the so-called impacting (effective) mass, which also cannot be measured directly.[32]

The role of kinetic or impact energy in injury development

Energy is one of the fundamental concepts of physics; numerous forms of its manifestation are known (e.g., kinetic, potential, elastic, thermal, binding, or collision energy). In understanding the mechanical background of injuries, the kinetic energy that is converted to the deformation of bodies, i.e., their shape change and motion state change, plays a key role based on the work theorem ($\Delta E_{total} = \sum W$).[33] If the attacked body region or body surface is not supported or in a fixed position, then the external force (e.g., a thrown object hitting the head) does not purely cause deformation of the target (e.g., in the form of laceration, skull fracture), but also partially accelerates the head and neck, as well as the trunk connected to the neck (i.e., the force also performs acceleration work). Staying with this example, particularly in assaults with rod-like, blunt objects, the energy that the perpetrator's muscle force converts into kinetic energy through acceleration is important, resulting in the victim being hit at high speed.[34] The following table shows the maximum achievable impact speeds of some characteristic blunt objects:

[32] Adamec, J. – Praxl, N. – Schneider, K. – Graw, M.: Estimation of effective mass of longish rigid instruments in head impacts. International Journal of Legal Medicine, Issue 2011/6. 763–771. o.
[33] Budó, Á.: Kísérleti fizika I. kötet – Mechanika [Experimental Physics, Vol. I – Mechanics]. Tankönyvkiadó. Budapest, 1986. 99–103. o.
[34] Trinh, T. X. – Heinke, S. – Rode, C. – Schenkl, S. – Hubig, M. – Mall, G. – Muggenthaler, H.: Maximum striking velocities in strikes with steel rods—the influence of rod length, rod mass and volunteer parameters. International Journal of Legal Medicine, Issue 2018/2. 499–508. o.

Blunt instruments	Gender	Max. impact velocities (m/s)	Max. impact velocities (km/h)
Aluminium rod (296 g, 100 cm)	Male	34,89	125,60
	Female	25,93	93,35
Aluminium rod (690 g, 100 cm)	Male	30,02	108,07
	Female	21,36	76,90
Wooden stick (452 g, 100 cm)	Male	31,56	113,62
	Female	23,63	85,07
Steel rod (1278 g, 100 cm)	Male	26,48	95,33
	Female	17,28	62,21
Wooden baseball bat (870 g, 86,4 cm)	Male	30,4	109,44
Aluminium baseball bat (840 g, 86,4 cm)	Female	31,8	114,48
Golf club head	Male	40	144,00
	Female	37,7	135,72
Earthenware beer stain (0,5 l)	Male	4,9-14,3	17,64-51,48
Glass beer stain (0,5 l)	Male	3,1-14,8	11,16-53,28

Table 1.
Maximum impact speeds of blunt objects frequently used in assaults, S*ource: T. X. Trinh et al. - Maximum striking velocities in strikes with steel rods—the influence of rod length, rod mass and volunteer parameters*

The effectiveness of such tools is significantly influenced by their mass, length, and mass distribution — based on these, the following main groups can be distinguished:[35]

- short (e.g., frying pan, glass bottle, wrench),

[35] Siegenthaler, L. – Sprenger, F. D. – Kneubuehl, B. P. – Jackowski, C.: Impact energy of everyday items used for assault. International Journal of Legal Medicine, Issue 2018/1. 211–217. o.

- medium length, uniform mass distribution (any rigid, rod-like object, such as aluminium pipe, spade handle, rods and sticks made from different materials),
- medium length, uneven mass distribution (e.g., golf club, hammer),
- long, heavy and uneven mass distribution (tools for specific tasks, such as spade, shovel, etc.).

The kinetic energy of these objects is proportional to their mass and the square of the velocity they achieve, and can be calculated with the following relationship:

$$E_{kinetic} = \frac{1}{2} \cdot m \cdot v^2$$

The development of injury and its severity — i.e., the potential injury hazard — can be interpreted as resulting from several interrelated physical factors. From the perspective of impact effects, the geometry of the injury-causing object and the injured area, collision speed, effective impacting mass, impact surface size, as well as collision time and deformation path length are essential. All these factors influence energy density, i.e., the amount of energy required to cause the injury when absorbed in a given surface or volume. Although precise estimation would require consideration of material properties (elasticity, hardness, internal structure), in practice, in accordance with forensic medical methodological recommendations, impact energy is a useful quantity for illustrating injury hazard. This kinetic energy can be transmitted actively during assault, with or without tools, e.g., by hitting, kicking, or stabbing, as well as passively when striking an object or surface. The toolkit of physics and ballistics enables objective comparison of the danger posed by various everyday objects based on the energy absorbed per unit surface area or per unit volume—for example, using the minimum energy required to fracture human bones. The following tables contain the impact speed and kinetic energy of such objects - including rod-like tools frequently used in assaults - in comparable form:

The moving object	Mass (kg)	Velocity (m/s)	Velocity (km/h)	Kinetic energy $\frac{1}{2} \cdot m \cdot v^2$ (J)
(puff tonometry) **air**	$5{,}5 \cdot 10^{-7}$	9	32,4	$2 \cdot 10^{-5}$
eye drop	$6 \cdot 10^{-5}$	1,2	4,32	$4 \cdot 10^{-5}$
champagne cork	$9 \cdot 10^{-3}$	30	108	4
paintball	$3 \cdot 10^{-3}$	70	252	7
squash ball	$2{,}4 \cdot 10^{-2}$	45	162	2,4
racquetlabda	$4{,}2 \cdot 10^{-2}$	45	162	4,2
tennisball	$5{,}7 \cdot 10^{-2}$	45	162	5,7
baseball	$1{,}5 \cdot 10^{-1}$	40	144	120
golf ball	$4{,}6 \cdot 10^{-2}$	76	274	130
.22 caliber rifle bullet	$3 \cdot 10^{-3}$	344	1239	170
water balloon	$3{,}5 \cdot 10^{-1}$	38	137	250
416 Magnum rifle bullet	$2{,}6 \cdot 10^{-2}$	730	2628	6900
automobile	$1{,}9 \cdot 10^{3}$	27	97	692000

Table 2.
Kinetic energy of various objects in increasing order [36]
Source: Bullock et al. - Ocular and Orbital Trauma from Water Balloon Slingshots.

[36] Bullock, J. D. – Ballal, D. R. – Johnson, D. A. – Bullock, R. J.: Ocular and orbital trauma from water balloon slingshots. *Ophthalmology*, Issue 1997/5. 878–887. o.

Different rods	Mass (kg)	Velocity (m/s)	Velocity (km/h)	Kinetic energy $\frac{1}{2} \cdot m \cdot v^2$ (J)
Light aluminium pipe	0,151 (0,136-0,168)	34,89 (29,77-46,06)	125,60 (107,17-165,82)	92,7 (67,3-144,2)
Wooden stick	0,233 (0,176-0,286)	31,56 (25,14-41,64)	113,62 (90,50-149,9)	109,9 (78,2-151,0)
Aluminium pipe	0,326 (0,232-0,356)	30,02 (24,92-39,60)	108,07 (89,71-142,6)	145,4 (102,8-182,1)
Steel pipe	0,563 (0,401-0,632)	26,48 (20,68-46,06)	95,33 (74,45-165,82)	194 (134,7-269,0)
Aluminium pipe, hitting zone at 0,94 m	0,151 (0,131-0,168)	34,89 (29,77-46,06)	125,60 (107,17-165,82)	92,7 (67,3-144,2)
Aluminium pipe, hitting zone at 0,68 m	0,278 (0,247-0,317)	25,78 (22,28-30,28)	92,81 (80,21-109,01)	92,4 (70,8-127,9)
Aluminium pipe, hitting zone at 0,44 m	0,647 (0,554-0,778)	18,43 (15,48-20,79)	66,35 (55,73-74,85)	107,4 (91,6-125,2)
Steel pipe with reloctable mass at 0,44 m	0,645 (0,478-0,770)	23,00 (17,69-32,50)	82,80 (63,68-117,00)	168,2 (129,1-282,6)
Steel pipe with reloctable mass at 0,70 m	0,811 (0,591-0,942)	22,16 (16,56-30,95)	79,78 (59,62-111,42)	196 (129,1-282,6)
Steel pipe with reloctable mass at 0,95 m	0,930 (0,656-1,099)	21,42 (16,43-30,82)	77,11 (59,15-110,95)	208,4 (143,6-311,5)

Table 3.
Impact speed and kinetic energy of rod-like tools were determined in experiments
Source: F. D. Sprenger et al. – The influence of striking object characteristics on the impact energy.

Summary

The concept of "force" plays a central role in legal practice in all cases where the human body is subjected to external mechanical effects and injury results. In criminalistic practice, the magnitude of force may arise as a professional question primarily in connection with violent events — falling, hitting, kicking, collision, stabbing — whether it concerns accidental, incident-like or intentional acts, suspicion of harm by others or self-harm. Although, as physics experts, our natural aspiration is quantifiability, in the analysis of specific cases — due to the lack of uniform measurement procedures and numerous unknown variables — precise determination of force magnitudes is usually only possible approximately, or not at all. Moreover, force values expressed in newtons are often difficult for laypeople to interpret on their own, especially when their magnitudes vary widely. Significant differences can also be observed in measurement methods across

the medical and forensic literature, and the diversity of constitutional characteristics, applied tools, and circumstances of assault decisively influences the assessability of the effects of force.

One of the aims of this study was to help appointing authorities formulate appropriate professional questions by clarifying fundamental physical concepts—particularly force and energy—and to contribute to the interpretability of professional answers. The presented theoretical foundations and practical examples hopefully advance the integration of the physics expert perspective into forensic medical expert work.

The other goal for the future is to develop methods that are reproducible and comparable from a natural scientific perspective, thus suitable for establishing a uniform forensic practice. To this end, we would like to collaborate with colleagues from the Institute of Forensic Medicine at the University of Pécs on the biomechanical examination of soft tissue injuries, and with forensic medical experts from HIFS and the Institute of Forensic Medicine at Semmelweis University on modelling injuries caused by 3D-printed weapons. These joint research projects may, in the long term, help strengthen the scientific basis of expert opinions.