BIOMECHANICAL ASPECTS OF STRIKING ACTIONS

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SUMMARY: A lot of assault striking motion action bring about the problem of determining and calculating possible hitting strength applied to the assault of the adversary. This paper presents mathematical formulas for the prediction of hitting power depending on several initial parameters. One of biomechanical factors of vital importance is the impact velocity of the arm on the adversary's body. There are no relevant data available so far. Our has been to determine different impact velocity experimentally in a sample of average male population. Precise measuring has show local impact velocities in the final 10 cm section of the trajectory before the impact. These data are presented in easy-to follow tables. The value of impact velocity provides information on the value of the strength of the impact.

KEY WORDS: Biomechanics; Velocity; Stroke.

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INTRODUCTION

The forensic application of biomechanics deals with the decoding of relevant criminalistic information originating in the vestige of penal action reflecting the functional and dynamic characteristic of the offender's or some other person's organism. The possibilities of application in accordance with the acquired experiences and literary research might be introduced below:

1. The assessment of the biomechanical content of the selected criminalistic vestiges; the up-to-now mostly analysed is the biomechanical content of the traseological phenomena, partly even graphological print. Among these biomechanical applications might be classified even the mechanical behaviour of the offender, his energetic output connected with the criminal act and his potential performance of movement viewing his abilities and limits of movement.
2. The extreme mechanical loading of organism, e.g. hitting by fist, stick or by some other object. Most frequently the attack is directed on the head of the victim. Analysing these facts one must state whether the attacked person died instantly or survived and theoretically might have been rescued. It is important to determine and quantify the limit

for possible survival after this cerebral mechanical loading of the victim's head structures.

3. The biomechanical estimation of falls from height most often out of the house window. It happens very frequently that the aggressor attack with the intention to kill and he throws the victim out of the window; during the investigation he defends himself by stating that the victim fell out by some unhappy chance. The biomechanical analysis may elucidate the fact of the involuntarily falling down or that there was an impulse and then that the victim was thrown out.

In this contribution we would like to concentrate on the extreme mechanical load of the victim's head and on the tolerance of man's organism. Under the extreme dynamic situations is to be understood the toleration and resistance to the supercritical quantities of force, acceleration and pressure causing the injury of the organism, which might or could not be survived. Here we speak about lethal injuries. The limits of toleration being rather broad and individual the kinematic and dynamic analysis seems necessary together with the individual casuistic excess.

Among the very frequent injuries, we meet in criminological practice, are the head injuries caused by a blunt object. These blunt head injuries are significant partly for their exposed position and partly because nearly each time the attacked body part comprises a vital organ.

EXPERIMENTAL DATA FOR DIFFERENT HEAD INJURIES

Mogutov's experiments examined the strength of the strike and the subsequent characteristics of injury in corpses in 76 experiments distributed into three groups according to the spherical radius of the hitting device (3, 6 and 8 cm).

The analysis of the mentioned head injury enabled to formulate four basic groups characterised by the quantity and volume of injury. According to the analysis of the mechanical loading of cadaverous skulls we introduce a survey in tables that follow.

The first group is represented by the stab injury, the second by crater shaped wound geometrically copying the spherical object, the skull does not crack (break) only depression arises.

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	9 986	0.68
6	6 605	0.63
8	12 691	0.68
Medium value	9 761	0.66

The second group of:

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	7 457	0.53
6	7 183	0.51
8	8 389	0.57
Medium value	7 677	0.54

The third group creates a crater with radial infractions and the forth group with craters with transversal and radial infections.

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	6 889	0.44
6	6 664	0.42
8	7 330	0.40
Medium value	6 961	0.42

The fourth group:

Diameter of the spherical object [cm]	Strength of strike [N]	Bone thickness [cm]
3	7 428	0.45
6	7 311	0.44
8	6 978	0.37
Medium value	7 239	0.42

The second and third group of injury are characterised by the crater with dimensions, diameter and length may be precisely measured. These data are introduced in further table.

Diameter of the spherical object [cm]	Second group of injury [cm]		Third group of injury [cm]	
	Maximum	Minimum	Maximum	Minimum
3	2.2	1.8	2.5	2.3
6	2.6	2.5	3.4	3.0
8	3.0	2.8	3.8	3.4

We have only inadequate information on the motion velocity of the arm in striking action from sports and combat actions. We have always measured the whole time of the motion, of the completed motion action from its start till it has been finished when the hand has touched its target or reached its culminating motion. In order to conduct precise biomechanical assessment it is necessary to know the momentous impact velocity of the hand on the chosen target. Data on this final limit velocity of the arm and hand are yet unknown.

The value of momentous velocity of the strike by hand or by object (load) is necessary for prediction and calculation of the strength of the strike and consequent characteristics of the injury. That's why we have conducted our own measuring aimed at determining the momentous velocity of the hand in certain types of striking motion. The measuring has taken place in the criminalistic laboratories of the Police Academy of the Czech Republic on special equipment monitoring times of the motion of the arm at constant determined distances from the impact surface. We have chosen a fixed distance of 10 cm from the impact surface.

We have conducted the experiment with group of 30 men a aged 21–45, of a standard somatic type the body height was chosen with the aim to divide the men into 3 groups according to the body height of 170 cm (10 persons), 180 cm (10 persons), 190 cm (10 persons), the variation being ± 2 cm. No participant has been extensively physically trained in any kind of sport.

We have divided the motion actions into two groups, labelling those striking actions where the strike had taken place without previous preparation index 1, with the frontal position of legs. Index 2 labels striking action where the stick took place from the lookout, the assailant being ready with the intention to strike. The starting time of the motion was subject to every participant's choice.

For the tables below we shall mark:

- t_1 – duration of the motion action within the last 10 cm of trajectory before the impact, the strike being conducted without preparation;
- t_2 – duration of the motion action within the last 10 cm of trajectory before the impact, the strike being conducted from the position of the combat alert, the assailant being ready with the intention to strike;
- v_1 – final velocity of striking action for option 1 when the strike took place without preparation, frontal position of legs;
- v_1 – final velocity of striking action for option 1 when the strike started from the position of combat alert, the assailant ready with an intention to strike.

TABLE I. THE HIT STRIKE COMING FROM ABOVE, CURVED TRAJECTORY

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.042	0.028	2.3809	3.5714
190	92	70	0.021	0.013	4.7619	7.6923
170	62	56	0.024	0.021	4.1666	4.7619

TABLE II. THE STRIKE COMING FROM ABOVE, CURVED TRAJECTORY, LOAD 1 KG

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.081	0.056	1.2345	1.7857
190	92	70	0.079	0.046	1.2658	2.1739
170	62	56	0.083	0.065	1.2048	1.5385

TABLE III. THE STRIKE COMING FROM ABOVE, UPPER ARM LEVELLED, FIST ABOVE SHOULDER, NO LOAD

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.054	0.026	1.8518	3.8461
190	92	70	0.065	0.026	1.5385	3.8462
170	62	56	0.023	0.024	4.3478	4.1666

TABLE IV. THE STRIKE COMING FROM ABOVE UPPER ARM LEVELLED, FIST ABOVE SHOULDER, LOAD 1 KG

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.063	0.038	1.5873	2.6316
190	92	70	0.061	0.036	1.6393	2.7777
170	62	56	0.082	0.045	1.2195	2.2222

TABLE V. DIRECT HIT BY A FIST, NO LOAD

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.031	0.022	3.2258	4.5454
190	92	70	0.034	0.031	2.9411	3.2258
170	62	56	0.038	0.031	2.6316	3.2258

TABLE VI. DIRECT HIT BY A FIST, LOAD 1 KG

Body height [cm]	Body weight [kg]	Length of arm [cm]	t_1 [s]	t_2 [s]	v_1 [m/s]	v_2 [m/s]
180	78	68	0.067	0.054	1.4925	1.8518
190	92	70	0.085	0.059	1.1765	1.6949
170	62	56	0.12	0.089	0.8333	1.1236

DISCUSSION OF RESULTS AND CONCLUSION

The experimental data are necessary to the assessment of the biomechanical model of the tolerance of organism to the dynamical loading. The validity of this model depends on the variability of data acquired.

The most realistic variant of the mathematical model would certainly be appropriate to compare the results with empirical data. These possibilities are rather very limited as the corresponding data concerning the mechanical qualities of skull and brain substance are not available and the standards describing the brain injury are not known. Up to now the best expression of the critical values is under "Wayne State Curve" described by Hicling-Wenner [2]. The mentioned curve describes the situation of a direct hit (stroke) of the head against a flat blunt object, and vice versa. The mentioned curve may be expressed as the time integral of an algebraic function, of the acceleration $a(t)$, i.e.:

$$GSI \quad {}_{0}^{t}\; a^{25}(\;)d\;, \qquad \{1\}$$

where the quantity *GSI* represents the skull loading stands for the acceleration.

The quantity *GSI* signalises, from the empirical point of view, that any overcoming of its critical value ($GSI \geq 1000$) give rise to a very dangerous blunt impact. The load value of such head injury is represented by the function of acceleration. Some empirical data for short pulsatory intervals (2 – 5 ms) were obtained from experiments with corpses in which the skull fracture was taken as criterion of tolerance. For longer pulsatory intervals (approximately more than 40 ms) the data from volunteers tests were used in which case the light degree of brain commotions or unconsciousness served as criteria. The average pulsatory intervals were based on experiments with animals (dogs and apes).

The intracranial pressure following the strike changes along the atheroposterior axis at the impulse duration till 2 ms. At lower values (t = 0.1 ms) has the pressure directly under the loading point a positive value, the interference does not reach the posterior part of the skull. At the strike by a blunt and solid object on the skull the pressure spreads in the interior and after certain time the pressure wave returns from the posterior wall and this pressure is denominated as negative pressure. This negative pressure reaches its highest values for $t = 0.8$ ms. The highest negative pressure is on the posterior wall of the skull – of which fact follows, that the brain mass could be easily damaged by the tension or compression and the region on the contralateral part of the skull towards the loading point demonstrates higher degree of damage than the region of the stroke.

The type of the stroke in Wayne State Curve does not always correspond to the model and physical reaction (unconsciousness, commotion) is not precisely understood. No criteria exist to clarify the brain injury. The time interval of loading seems to approximate most precisely the criterion of brain injury. The negative pressure value in brain tissue depending on the intensity and duration of loading would sufficiently describe the process. Important data were obtained at loading tests carried out on fresh dead bodies after the autopsy in the range of frequencies 1–350 Hz [2]. In order to calculate the influence of pressure in duration of some milliseconds it is necessary to know the loading function in the frequency interval from 0 to 2200 Hz. The time limit of load duration is 0.0022 s which load corresponds to the stroke action.

The experimentally reached results enlarge the contemporary basis of knowledge in biomechanics, criminalistics and forensic medicine.

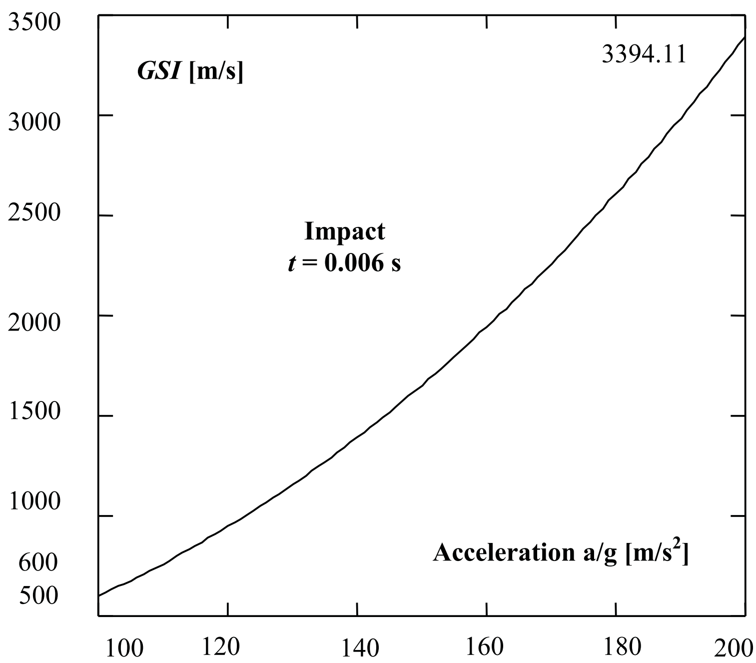

Fig. 1. GSI plotted as function of acceleration at $t = 0.006$.

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