THIS DOCUMENT CONTAINS
35 PAGES, COPY NO. 1
OF 5 COPIES.

NON-PENETRATING IMPACT
AS AN
AGENT FOR PERSONNEL INCAPACITATION

Prepared by:

31 January 1972

245

This report has been prepared by the as a part of a Government contract. The views expressed are those of personnel and not necessarily those of the United States Government.

TABLE OF CONTENTS

	Page
Protocol Statement	i
List of Figures and Tables	iii
Problem	1
Introduction	1
Discussion	2
I. Potential Applications for Incapacitation	2
II. Physical Variables of Impact	4
III. Physiological Considerations	7
A. Impact as a Reaction	7
B. Physical Basis for Biologic Effects	8
C. Biologic Effects	9
D. Thresholds	11
E. Physiological Conclusions	21
IV. Other System Factors	23
A. Range	23
B. Covertness	23
C. Duration of Incapacitation	23
D. Countermeasures	24
V. Equipment State of the Art	25
VI. Recommendations	28
References	30

LIST OF FIGURES

		Page
Figure 1.	Factors of the Reaction Between an Impacting Object and the Human Body . . .	7
Figure 2.	Approximate Acceleration -- Injury Correlation of the Study by Higgins, et al	13
Figure 3.	Suggested Approximate Thresholds for Impact Effects on the Head Under Laboratory Conditions	14

LIST OF TABLES

Table I	Metric Units of the Fundamental Dynamic Factors of Impact	6
Table II	Hypothetical Results of a Well-Developed Concussion System Under Field Conditions .	16
Table III	Effects of Non-Penetrating Impacts on the Trunk	19
Table IV	Estimated Durations of Incapacitation for Non-Repetitive Impacts	24
Table V	Effects of Soft Plastic Projectiles Designed to Cause Concussion	26

NON-PENETRATING IMPACT AS AN AGENT FOR PERSONNEL INCAPACITATION

PROBLEM

To evaluate, especially from the physiologic point of view, non-penetrating impact as an agent for personnel incapacitation.

INTRODUCTION

For the purposes of this report, a non-penetrating impact is considered to be a relatively high-velocity collision between a blunt object and the human body, excluding those collisions that break the skin. The results of non-penetrating impact are usually classed as blunt trauma in the medical literature.

Healthy adult humans in the 45 to 90 kilogram weight range are assumed to be the subjects for incapacitation throughout this report.

DISCUSSION

I. Potential Applications for Incapacitation

Controlled impact can offer a number of advantages when compared to other proposed techniques for personnel incapacitation. Among the possible advantages are:

Spectrum of incapacitation: pain, muscle spasm, breathlessness, unconsciousness, severe injury.

Rapidity of incapacitation: onset of action within a second.

Directivity: with respect to person to be incapacitated.

Controllability: of time of onset and type of incapacitation.

Safety: for the operator.

Simplicity: of techniques and equipment.

Covertness: can be extremely quiet and unobtrusive.

Most of the incapacitating biologic effects of impact are critically dependent upon anatomic location, implying that an impact system would have to be aimed at a selected point on the subject's body by some means. Under field conditions, impact systems will probably not prove feasible for incapacitating a group of subjects at one time although a system might be capable of incapacitating a number of individuals in rapid succession. The aiming requirement also indicates that most systems would have to be controlled directly by an operator; any pre-set trap system would have to: (1) ensure that the subject will move precisely into a pre-determined position; or (2) be equipped with an elaborate automatic aiming subsystem.

Incapacitation by impact alone will usually be brief unless the operator is willing to risk severe injury or death of the subject. The rapid onset of incapacitation by impact makes it a natural choice for the initial "knockdown" technique, to be followed immediately by application of a different method of maintaining control of the subject if prolonged incapacitation is desired. In the prolonged incapacitation case, the requirement for prompt application of a second technique may prove to be a limiting factor in the range of projectable impact systems in that the operator(s) would have just a few seconds to approach the downed subject and apply the second technique.

Within these limitations, a variety of impact systems could be developed for general or specific application. Examples would be a hand-held "calibrated blackjack," a relatively long-range projectile "stun gun" or a hijacker trap installed on aircraft. The impact delivery system would be mechanically simple and reliable, using power from human muscle, springs, compressed gas, pyrotechnics, or other sources. Repeat action could be developed for use against multiple subjects.

II. Physical Variables of Impact

Impact is collision, the forceful contact of two objects that have moved together. In an elementary sense, the basic factors of impact are simple: the mass and structural characteristics of each object and their relative velocity just before impact. In most practical situations, a detailed engineering analysis of an impact situation would require that a large number of variables be considered and a complete description of the event would be extremely complex. A major complication in most impact analyses is that a number of important variables change rapidly and interdependently during a short time period.

In a simple impact case, two objects approach each other at a known velocity and in a known geometric relationship. Both objects start to be deformed at the first moment of contact, and pressure and shear waves start to travel through both objects. The area of contact between the objects becomes larger as a result of deformation to "fit," although pressure usually remains highest at the centerpoint of the contact area. Momentum is conserved and transferred between the objects. Kinetic energy is conserved, transferred between objects, stored as potential energy, or dissipated as sound, frictional heat or disruption of one or both objects. Both objects accelerate; usually both objects are subject to combined linear and angular accelerations. If a sufficiently strong elastic component is present in the interaction, the objects will be forced apart and the area of contact will become smaller as one or both objects release potential elastic energy and start to restore their original shape. Impact is complete as soon as kinetic energy transfer is complete and the two objects are moving together as a unit (like a ball of putty thrown so as to stick on a wall) or have broken contact to move independently again.

Detailed analysis of the reaction described above would not be a simple matter even with the simplest sort of homogeneous masses moving as "isolated systems" in the ideal physical sense, or with perfect billiard balls moving on a perfect billiard table. When one of the objects is as inhomogeneous, complex and irregular as the human body, the problem of impact defies detailed analysis except for minor extrapolations of empirical data. Any systematic treatment of the human body in impact must consider the body as a number of masses connected in a variable geometry by supporting structures with rapidly varying mechanical characteristics. A blow to the head of a man reading a book is likely to have an effect quite different from the same blow delivered to the same man by an opponent in the boxing ring.

Table I briefly defines fundamental dynamic units of impact factors, in the metric system. Non-metric units commonly found in the impact literature are: "atmosphere" of pressure equal to about $1.01 \cdot 10^6$ dynes/cm^2; "G" of acceleration equal to about 980 cm/sec^2; the English unit "pound" has been confusing because it may be used as a unit of mass or a unit of force. All of the factors noted in Table I are vector quantities except for mass and kinetic energy.

This report will not deal specifically with the factors that determine the structural characteristics of colliding objects. The various moduli, strengths, viscosities and impedances that quantitatively define the compressibility, plasticity and elasticity of structures in the human impact context have been reviewed by von Gierke.[1,2]

TABLE I

METRIC UNITS OF THE
FUNDAMENTAL DYNAMIC FACTORS OF IMPACT

Factor	Definition	Unit	Equivalent
Mass	Inertial characteristic of matter; proportional to "weight" in gravity field	gram	--
Velocity	Rate of change of position	cm/sec	--
Acceleration	Rate of change of velocity	cm/sec^2	--
Jolt [3]	Rate of change of acceleration	cm/sec^3	--
Momentum	Product of mass and velocity; also, product of force and time	gm-cm/sec	--
Force	Product of mass and acceleration	dyne *	$gm\text{-}cm/sec^2$
Onset [3]	Rate of change of force; also, product of mass and jolt	dyne/sec	$gm\text{-}cm/sec^3$
Pressure	Force per unit area	barye	$dyne/cm^2$
Kinetic energy	Work capability due to motion; product of force and distance	erg **	$gm\text{-}cm^2/sec^2$

*One Newton is 10^5 dynes

**One joule is 10^7 ergs.

III. Physiological Considerations

A. Impact as a Reaction

The physical and biological consequences of impact are determined by the reaction between the impacting object and the human body. Figure 1 indicates a number of the factors and subfactors that enter into and modify the reaction. Primary impact factors are those related to the initial contact

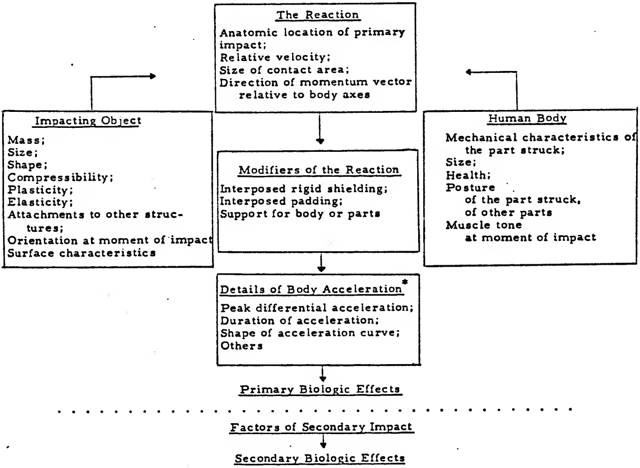

Figure 1. Factors of the Reaction Between an Impacting Object and the Human Body.

---

* Including both linear and angular accelerations.

between an impacting object and the body. Secondary impact would be any subsequent impact events which might occur as a consequence of the first. Examples of secondary impact would be collisions between: (1) the same impacting mass and a second body part; (2) two body parts; or (3) some body part and a second object, such as a floor or wall.

Consideration of Figure 1 leads to the conclusion that many of the variables important to an impact problem are interrelated in a complex manner, and suggests that many factors can be critical with regard to the biologic outcome of any given impact situation.

B. Physical Basis for Biologic Effects.

Most of the biologic effects of impact are due to mechanical deformations of body tissues. These deformations are the result of forces arising from differential acceleration of body parts. The forces may tend to compress, expand, bend, shear or twist the tissues. The force pattern is usually complex and changes rapidly with time. Oscillations may travel to body areas away from the site of impact in the form of compressional or shear waves, and oscillatory action could persist for a short time.

Pre-impact momentum is conserved when the post-impact vector velocities of both the impacting object and the body are considered. These velocities also constitute part of the energy that is conserved through the impact event. Part of the kinetic energy of impact is converted to frictional heat from: (1) deformations of the impacting object and the body; and (2) contact with the air and other surrounding materials. More of the kinetic energy may be absorbed in structural disruption or converted to potential energy or sound.

The physical effects of impact on living systems may be summarized as: (1) short term deformations; (2) longer term deformation including structural disruptions; and (3) heating, usual minor. Redistribution of body fluids and other effects only become significant when unidirectional accelerative forces persist longer than a second; these effects are beyond the scope of this report.

C. Biologic Effects.

Most of the biologic effects that might be desired for temporary incapacitation of personnel are caused by the short-term deformations of tissue, especially those with rapid onset. A forceful push will not be as effective as a sharp blow for incapacitation purposes.

The most dramatic transient effects of impact are those on nervous and muscular tissues. Appropriate rapid deformation of these "irritable" tissues can cause depolarization ("firing" of nerve cells, contraction of muscle fibers) and an alteration of the functional status of the tissues for some time after the blow. This is the mechanism of all the commonly experienced effects that start with great rapidity following impact. Firing of nerve fibers in the skin and deeper structures causes the immediate pain at the site of impact, as well as effects like the tingling pain that shoots down the forearm from a blow on the "funny bone," (the ulnar nerve at the elbow). Rapid compression of muscle tissue is presumed to be the cause of the "charley horse," a painfully persistent mass of spastic muscle resulting from a blow. The display of lights "seen" by a person receiving a sub-concussive blow on the head is apparently caused by direct mechanical stimulation of the visual cortex of the brain; a similar display can be induced by experimental electrical stimulation of the visual cortex. Concussion, the sudden loss of consciousness immediately following a blow to the head, is presumed to be caused by short-term mechanical deformation of the central nervous system. Electroencephalographic and animal studies indicate that concussion is due to functional changes in vital hindbrain centers. These same studies also indicate that certain phases of the concussion-recovery sequence include suppression of basic reflex activities, and other phases resemble natural deep sleep and awakening.[4,5]

Longer term effects of impact may include: (1) alteration in the permeability of vascular systems near the impact site; (2) disruptions of blood vessels; (3) dislocation and/or breakage of structures other than blood vessels. The permeability changes account for swelling, aside from lumps of spastic muscle, without discoloration. Breaks in blood vessels cause the subcutaneous hemorrhage of a simple contusion or bruise, as well as more serious losses of blood from the vascular system. Bones, cartilages and teeth are subject to dislocation by impact. Organs seriously injured by blunt trauma are usually classified as: skin and subcutaneous tissue; skeletal muscle; the complete skeleton including cartilage and teeth; heart and great vessels; the "hollow viscera" including the gastro-intestinal, biliary and lower urinary systems; the "solid organs" including brain, liver, spleen and kidneys; and special organs such as lungs, eyes, genitalia and larynx. Impact can cause chain reactions of injuries such as a blow to the chest which fractures ribs in such a way that the rib fragments cut blood vessels and membranes covering the lungs. The latter injuries can lead to serious internal hemorrhage and potentially fatal lung collapse. Laceration of the liver or other solid organs can cause massive internal hemorrhage and perforation of any hollow viscus leads to a life-threatening peritonitis. Either of these latter injuries, along with bleeding inside the skull and any injury that prevents adequate respiration, will usually be fatal unless medical care, including major surgery, is available promptly.

Frictional heat of impact may play a part in the biologic effects of high velocity low momentum impacts, such as a painful switch on the skin with a lightweight whip. Although the possible abrasive component of such a blow is difficult to evaluate, enough heat energy from the impact may be dissipated in the skin to cause some of the observed local effects. A whip mark can resemble a thermal burn in many ways, with painful red swelling and tendency to blister and peel. It is interesting to speculate that any rapid change in skin energy level tends to evoke a similar type of response, regardless of whether change is due to heat, cold, friction, electricity, ionizing radiation or high velocity impact.

D. Thresholds.

For the purposes of the personnel incapacitation problem, the desired effects of impact would seem to be limited to: (1) concussion or other sudden decrement in level of consciousness; (2) transient paralysis including apnea; and (3) pain or the threat of pain. The other effects noted in the previous section of this report either would not contribute to prompt incapacitation of the subject or would constitute a potentially serious injury to the subject. Some results of impact could be both ineffective and dangerous; a crippling or life-threatening wound might not necessarily be rapidly incapacitating unless it also had sufficient effect in at least one of the three categories noted above. The remainder of this report will assume that impact is to be arranged so as to maximize the three potentially incapacitating effects and to minimize all of the other effects.

Concussion without other damage could be a rapid and thorough type of incapacitation. Scientific attempts at evaluation of the factors and thresholds of concussion started well back in the last century and continue to present. Evaluation techniques have ranged from analyses of accidents and sporting events to postmortem studies and carefully controlled impacts deliberately delivered to the heads of experimental animals. The results of all these investigations may be summarized as follows:

1. The detailed mechanism or mechanisms leading to concussion remain a matter of debate. Some hypothetical mechanisms which have been advanced are as follows:

(a) Local skull deformation with local pressure effects;

(b) Increased overall intracranial pressure;

(c) Differential intracranial pressure;

(d) Differential pressure across the foramen magnum;

(e) Shear forces across the brain stem;

(f) Linear acceleration of the whole head;

(g) Angular head acceleration causing differential motion between brain and skull;

(h) Cavitation;

(i) Flexion-compression phenomena at the craniospinal junction and,

(j) Overstimulation of neck proprioceptors.

Several of these hypotheses have been more or less disproved, at least in certain experimental circumstances, by later investigations. There is no generally accepted mechanism or group of mechanisms for concussion.

2. There is general agreement: that alteration of function of structures in the hind brain and brain stem is a sine qua non of concussion; that a head free to move relative to the neck and shoulders is more subject to concussion than a firmly supported head; and that repeated concussive blows greatly increase the likelihood of serious injury or death.

3. Even with meticulous laboratory attempts to control all of the variables indicated in Figure 1, no investigator has been able to establish precise thresholds between non-concussion and concussion, or between concussion and more serious injuries. This failure is linked directly to the lack of understanding noted in paragraph 1 above.

The careful work of Higgins, et al illustrates the difficulties involved in 6
attempts to define a predictable relationship between impact and concussion. These investigators delivered calibrated, aimed impacts to the precisely oriented heads of twenty-five monkeys that had shaved scalps "potted" in plaster inside metal helmets. This elaborate preparation brought under control many of the variables noted in Figure 1. Even under these special conditions, with skull deformation a virtual impossibility, the authors were unable to calculate impact characteristics that would reliably cause concussion without other serious injury. The concussive results were reported

not in terms of standardized impact "doses" but in terms of measured angular acceleration imparted to the head. The reported results of the study are approximately summarized in Figure 2.

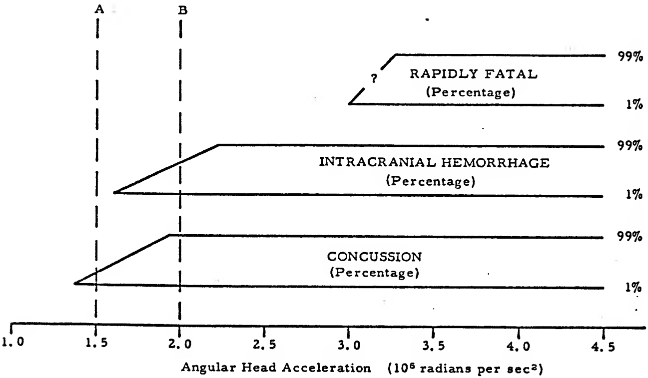

Figure 2. Approximate Acceleration -- Injury Correlation of the Study by Higgins, et al.

Figure 2 indicates that under the extremely rigid artificial test conditions an acceleration level "A" could have been preselected to yield rates smaller than 1% for serious injury or death in conjunction with "successful" concussion rates on the order of 25%. Acceleration level "B" could have been expected to yield a concussion rate of 99% with a serious hemorrhage rate of about 50% and a rapid death rate still below 1%. The thresholds indicated by Figure 2 would have been even broader and more overlapping if the investigators had been forced to relate the effects directly to some measurement of the delivered impact, rather than to the resultant head acceleration.

Admitting that their results give only the roughest approximations of thresholds, most other investigators have found that velocity of impact is as useful as any other single index in predicting effects on experimental animals when the mass of the impacting object, anatomic location and other factors are kept as constant as possible. The impacting object is commonly assumed to have a mass about equal to the weight of the head and neck of the experimental animal, or about 5 kilograms in the case of adult humans, and may be assumed to have the structural characteristics of a compact block of wood without sharp edges. Using these and other criteria, suggested approximate thresholds for impact effects on the head are shown in Figure 3.

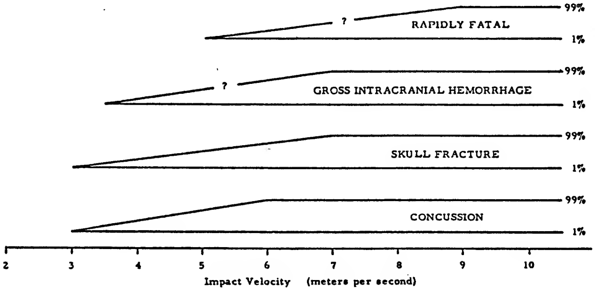

Figure 3. Suggested Approximate Thresholds for Impact Effects on the Head Under Laboratory Conditions. 6, 7

The thresholds indicated by Figure 3 are approximately the same as those suggested for situations in which the head is rapidly decelerated by striking large objects such as the ground or structure of buildings or vehicles.[7]

Velocity of impact is the independent variable shown for Figure 3, although the stipulation that the impacting object has a mass on the order of 5 kilograms defines the abscissa in terms of momentum also. Experienced investigators of the biologic effects of impact tend to agree that: (1) there is no single mechanical unit that provides an optimum measurement of the biologic "dose" of impact; and (2) velocity and/or momentum come closer than any other units to providing satisfactory correlations over a wide range of conditions. Kinetic energy correlations break down at the low-mass end of the scale where high velocity objects penetrate the skull without causing concussion, and at high-mass end of the scale where biologic effects seem to be more in proportion to velocity than to energy. Acceleration or force values correlate to biologic effects only when the duration of action is taken into consideration. As indicated by Table I (page 6), integration of acceleration or force with respect to time yields units similar to velocity or momentum. Detailed evaluation of mechanical impact events can be derived only from high-speed recording of some factor(s) in the displacement-velocity-acceleration spectrum from multiple sites around the head. Of the many possible single mechanical values, velocity seems to retain fairly uniform biologic significance over a wide range of conditions. Even momentum has a limited range: the impact effects of a slowly rolling automobile are quite different from the impact effects of a small lead pellet with momentum equal to that of the automobile.

Figure 3, as imprecise as it is, must be considered as only the roughest guide to impact thresholds, and only under laboratory conditions. The experimental conditions under which these thresholds were measured usually included absolute control over the posture and orientation of the subject with respect to the impact. Such control implies <u>previous incapacitation</u>

of the subject by some means, usually anesthesia and/or physical restraints. Control of subject posture, orientation and other factors shown in Figure 1 (page 7) would be even more difficult under field conditions than it is in the laboratory. The net effect of such variability could only be to widen and increase the overlapping of the already broad thresholds shown in Figures 2 and 3. No numerical data from impact studies under actual or simulated field conditions are available. An impact incapacitation system might be developed that could yield results similar to those shown in Table II under selected field conditions.

TABLE II

HYPOTHETICAL RESULTS OF A WELL-DEVELOPED CONCUSSION SYSTEM UNDER FIELD CONDITIONS

Effects	Impact Levels		
	A	B	C
Concussion	5%±	50%±	95%±
Non-Concussion	95%±	50%±	5%±
Skull Fracture	< 5%	10 - 40%	> 50%
Serious Hemorrhage	< 5%	10 - 40%	> 50%
Rapid Death	< 1%	1 - 10%	> 10%

On the basis of presently available information, the hypothetical rates shown in Table II may even be overly optimistic with regard to the safety of blows to the head at concussive levels. It should be noted that Table II is concerned with intracranial effects only; injuries to eyes and other facial structures * would be a separate consideration in anterior blows to the head.

Non-penetrating impacts to the trunk offer no special advantages for

* The relative tolerance of human facial structures to impact has been reported by Swearingen. [8]

personnel incapacitation with the possible exception of the "solar plexus punch" to the epigastrium. This blow, familiar to participants in contact sports, causes the "breath to be knocked out" of the subject for periods ranging from a few seconds to as long as a minute. Characteristically, the subject remains relatively motionless in a doubled up position and is unable to breathe or speak until he recovers. The exact mechanism by which both diaphragmatic and intercostal breathing is inhibited remains unknown; the "solar" or celiac plexus of nerves to the intestines may or may not be involved. The blow usually has much of the mass of a player behind it and is most effective when the subject is not tensed to receive the impact. A typical solar plexus blow might be characterized as landing between the umbilicus and the xiphoid process, directed straight posteriorly or slightly headward, with an effective mass greater than ten kilograms and a velocity of several meters per second. Available reports mention no experimental work that would help to explain or quantitate the effectiveness of impacts delivered to the epigastrium.

The equivalent of a solar plexus punch would probably be difficult to develop into a safe and effective technique for personnel incapacitation. A perfectly delivered impact that had been calculated to incapacitate a man tensed to receive the blow could prove fatal if the subject does not tense in time. Errors in anatomic location and direction of impact would lead to decreasing effectiveness and increasing rates of serious injury and fatality. Properly directed but excessively powerful blows could kill by rupturing the aorta, diaphragm, stomach or other viscera. Blows slightly high could contuse the heart or cause lung collapse from rib cartilage fragments. Lateral aiming errors could cause rupture of liver, spleen or kidney. A low blow could rupture a full bladder or other lower abdominal structure.

Clemedson, et al have reviewed the relative tolerance of various body parts to blunt trauma, and come to the conclusion that liver, spleen and kidney are the organs most susceptible to severe injuries from flying missiles.[7]

Table III summarizes the scanty information available on injury thresholds for non-penetrating impacts on the trunk.

It should be noted that the effects shown in Table III provide no guide to the effectiveness of a blow in causing rapid incapacitation. Even the lethal impacts shown in the table might cause no significant incapacitation for several minutes. The only rapidly incapacitating effects that could be expected from a non-fatal blow to the trunk would be pain and the solar plexus effects discussed previously.

Impacts on extremities are unlikely to cause transient incapacitating effects other than pain. A blow that would pinch a peripheral nerve hard enough to cause a paralysis of the muscles served by that nerve is quite likely to destroy a section of the nerve. Long bones of the extremities can be broken by energetic direct blows. These so called "billy club" fractures are more common in the shin and forearm where the bones are not heavily padded with soft tissue. Wartime British investigators conducted tests with experimental animals and estimated that direct blows by a metal rod with kinetic energies in the 12 to 60 joule range should suffice to fracture the human humerus, with a mean energy of 27 joules.[9] The same group estimated that three times as much energy would be required to break the stronger and better padded human femur. If these estimates are correct, blows with masses less than a kilogram and with fairly low energies (on the order of 5 joules) could probably break the human fibula, radius or ulna under some circumstances. Even so, certain fractures of the fibula and other smaller bones may not be extremely painful, or otherwise incapacitating to the subject. "Safe" blows, therefore, could not be expected to cause much in the way of incapacitation.

Transiently incapacitating pain can be generated by appropriate impact anywhere on the body surface. Skin pain is caused by low mass, high velocity blows such as those delivered by a willow switch. Blows from slightly heavier objects can cause deeper pain if delivered to body areas where bones

TABLE III

EFFECTS OF NON-PENETRATING IMPACTS ON THE TRUNK *

(After Clemedson, et al)[7]

Impact Location	Moving Mass (kg)	Velocity (meter/sec.)	Effect
Lateral chest	0.18†	24	local lung hemorrhage
" "	0.18†	36	lacerations from rib fragments
" "			
" "	0.18†	52	rapidly lethal
" "	0.36†	13	local lung hemorrhage
" "	0.36†	27	lacerations from rib fragments
" "	0.36†	47	rapidly lethal
Over liver	15.5‡	2	minor liver damage
" "	15.5‡	4	threshold of severe damage
" "	15.5‡	6 - 10	rapidly lethal
Whole body *	70*	3	usually survive
" "	70*	6	threshold of lethality
" "	70*	8	50% lethal
" "	70*	9	near 100% lethal

* Clemedson implies that the data is applicable to the human trunk, although most of the experimental work was with animals.[7]

† Missile comparable to a croquet ball.

‡ Pendulum weight of unspecified "solid" material.

* Whole bodies thrown, presumably laterally, against an unspecified large solid surface.

or cartilages have only a shallow covering of soft tissues. This pain arises from the sensitive periosteal, or perichondreal, membranes covering bones and cartilages. The relatively hard material underlying periosteum makes the membrane susceptible to a pinching action from brisk impact with a hard object. Periosteum is usually shallow in the following body areas: skull, clavicles, extremity joints, shins, backs of hands and tops of feet.

Certain body areas deserve special comment with regard to impact sensitivity. The eyes and the laryngeal area are extremely sensitive to pain and impact, but blows that would be inconsequential elsewhere on the body could cause severe injuries in these two areas. The testicles are also extraordinarily sensitive to pain from impact, but are much less likely to be permanently damaged by a blow. Testicular pain is particularly suitable for incapacitation in that it is intense, prolonged and tends to keep the subject in a doubled up position. The fact that testicular function is not permanently impaired by intensely painful impact is indicated by the rarity of major testicular injury in contact sports where rigid shielding is not worn. 10

Peripheral nerves are pain sensitive organs but usually are too deeply buried in other soft tissues to be directly effected by non-penetrating impact; the only common exception is the "funny bone," actually the ulnar nerve at the elbow. As previously noted, impact to muscle can cause painfully persistent muscle spasm of the "charley horse" variety. Although scientific proof is lacking, current medical opinion regards the painfully "paralyzed" upper extremity from a "rabbit punch" or "karate chop" to the lateral base of the neck as voluntary immobilization of the extremity due to the painful spasm of shoulder muscles, rather than any direct effect on the deeply buried motor nerves to the extremity. Large volumes of muscles could be struck with relative safety as follows: buttock, thigh, calf and any aspect of the shoulder except the front and tip where bones are shallow.

E. Physiological Conclusions

Pain is the most easily obtained mode of "safe" incapacitation by non-penetrating impact. High velocity, low mass impacts anywhere on the skin surface can cause transient stinging skin pain with little risk of serious injury to the subject. Slightly heavier blows directed to bony areas can cause severe periosteal pain. Still heavier blows to large muscle masses can cause painful muscle spasm, and probably some degree of paralysis of the body part involved. The most incapacitating, relatively safe pain is probably that from testicular impact, with no comparable point of aim available in the female subject.

The painful apnea of a heavy low velocity blow to the epigastrium remains a medical enigma. The physiologic mechanism that stops all respiration is unknown and there is no quantitative information available to estimate the effectiveness of blows with varying mechanical characteristics. In general, blunt trauma to the abdomen leads to poorly predictable and sometimes fatal results. A highly developed system to incapacitate by "solar plexus punch" impact could possibly prove to be about 50% effective with only 20% serious injury and 5% mortality under favorable field conditions. Effectiveness could probably be raised, but only at the expense of increased morbidity and mortality. These figures are strictly speculative and the actual values of any system would have to be proved in field trials.

True cerebral concussion has been the subject of much medical, engineering and interdisciplinary study. In spite of all this effort, many aspects of the concussion problem continue to defy detailed analysis. The fact remains that the most able investigators, controlling a large number of variables, and using completely incapacitated experimental animals under carefully defined laboratory conditions, have been unable to define the head impact that will reliably cause concussion with only a low risk of permanent brain damage. This result will certainly not be achieved under field conditions until it has been achieved in the laboratory. At the present state of knowledge, it may be hypothesized that a concussion system 95% effective under favorable field conditions would cause permanent brain damage in about 50% and sudden death in about 10% of cases. Lesser hazard could probably be achieved at the expense of effectiveness.

The blow to the head might be put in a more favorable light if significant incapacitation could be proved for sub-concussive impacts. Most investigators mentioned above defined concussion in strict terms to mean a deep level of unconsicousness, often with the loss of certain basic reflexes. A smaller decrease in the level of consciousness might well suffice in certain personnel incapacitation situations. Available information does not allow any worthwhile estimates of the mechanical characteristics, effectiveness or hazard of such impacts.

Impacts to the face and anterior neck should not be used in most incapacitation situations. The likelihood of permanent injury to eyes, other facial structures or larynx would be high, and the area offers no special modes of incapacitation other than blindness which is likely to be permanent.

IV. Other System Factors

A. Range

All impact effects aside from skin pain will be initially dependent upon point of aim and the subject's orientation and posture. Such dependence is likely to restrict the range of impact systems severely, at least for systems that are reasonably reliable and offer some degree of safety for the subject under a variety of field conditions. A perfectly aimed low velocity missile will not hit properly if the subject turns or moves between the time of firing and the time of impact. At best, systems with ranges longer than arm's reach would seem to be useful only in situations where the subject is: (1) relatively motionless in the first place; and (2) unaware of the action being taken against him. Direct manual control, so that direction and velocity can be corrected continuously up to the moment of impact, would seem to be the only reasonably safe way to deliver a heavy blow to a moving and/or wary subject. At the present state of knowledge, systems causing skin pain are likely to be the only safe and effective ones having ranges greater than a few meters.

B. Covertness

Properly designed impact incapacitation systems should be relatively quiet and unobtrusive in operation. The subject's response is likely to be noisy except in cases where a concussive blow, the solar plexus punch or testicular impact had been used.

C. Duration of Incapacitation

Estimated durations of incapacitation by non-penetrating impacts are shown in Table IV.

TABLE IV

ESTIMATED DURATIONS OF INCAPACITATION FOR NON-REPETITIVE IMPACTS

Mode of Incapacitation	Estimated Duration
Pain:	
Skin	less than 5 seconds
Periosteal	less than 10 seconds
Testicular	5 seconds to several mins.
Muscle spasm	5 seconds to several mins.
Solar Plexus	less than 1 minute
Concussion	10 seconds to several hrs.

Light impacts, such as those causing skin or periosteal pain, can be safely repeated several times to extend the time of incapacitation.

D. Countermeasures

Appropriate armor and/or padding could be an effective countermeasure to an impact incapacitation system. Modern football helmets offer excellent protection against blows that would have devastating effects on a bare head. Rigid cup-like protectors could nullify the effectiveness of impacts to the genital region.

V. Equipment State of the Art

A number of projectile systems have been developed for the purpose of personnel incapacitation without lethality, if not without serious injury.[11-13] Other non-penetrating impact systems have been proposed.[14,15] Almost all of these actual and proposed systems have been based on inadequate design criteria with regard to "safe" incapacitating impacts because, as explained in the previous section of this report, mechanical design criteria do not yet exist for most of the desired biologic effects. With their masses in the 1 to 5 gram range and velocities over 100 meters per second, the Speer .38 and .45 caliber projectiles and the Wyle .38 caliber projectile would clearly be unsuitable from the biologic as well as the ballistic point of view.[11] The test data on the second generation Scimitar flechette indicate ballistic success and biologic failure in that virtually 100% of test missiles at least partially penetrated the biologic targets.[12]

The results of rather elaborate effectiveness tests on soft plastic projectiles hitting the heads of experimental monkeys and baboons are shown by Table V. Test series II and III were conducted using "improved" techniques modified as indicated by experience. The investigators regarded the results of the third series as good enough to warrant a basically favorable report on the approach. The results shown in Tabel V were not achieved under simulated field conditions but under rigid laboratory control, including prior complete incapacitation of each experimental animal for positioning purposes. Obviously the morbidity and mortality rates experienced during these three series of tests would not be acceptable for incapacitation of human subjects.

The difficulty of developing a device that will reliably cause concussion, regardless of other constraints, is illustrated by the special device for "knocking" cattle before bleeding in slaughter houses. This pistol-like device is hand held between the ears of the animal, aimed and fired. The blunt striker causes a depressed skull fracture, gross brain damage and,

TABLE V.

EFFECTS OF SOFT PLASTIC PROJECTILES DESIGNED TO CAUSE CONCUSSION

Test Series	I	II	III
Number of animals			
Incapacitated * (percentage)			
Not Incapacitated (percentage)			
Skull fracture (percentage)			
Rapidly lethal (percentage)			

* for 5 seconds or longer

hopefully, concussion. In the small test series reported, skull fracture and brain damage were achieved in all cases but 16% of the animals continued to struggle after the first "knock" and required a second shot.[16]

Available information suggests that the only sophisticated device that has been proved to satisfy in any degree the objective of this report is the Remington "Stinger" 12 gauge shotgun load. This cartridge fires about 350 polyethylene spheroids about 3 millimeters in diameter and weighing about 0.02 gram each from a standard shotgun at unstated velocity. The manufacturer recommends that the load be aimed at the ground about a meter in front of the subject so as to ricochet and strike the subject below the knee only. Reported test results indicate: (1) gross tissue destruction at ranges of 3 meters and less; (2) brief incapacitation by pain without serious injury at ranges between 5 and 10 meters; (3) no effect at ranges greater than 15 meters; and (4) appropriate clothing would be an effective countermeasure at all ranges greater than 5 meters.[11]

Some ancient weapons could satisfy the requirements for "safe" incapacitation by pain if they are properly used. The police baton is a case in point. Standard batons in the United States are hickory cylinders about 3 centimeters in diameter and 65 to 92 centimeters long, weighing 380 to 525 grams.[17] Wielded at peak velocities of 5 to 10 meters per second, these instruments could clearly be lethal if used indiscriminately. Recommended police baton procedure is to threaten, push, or strike the subject below the knee. Blows to the head are to be avoided if at all possible.[18] Broken bones are a definite possibility with heavy blows from a baton.

Handheld instruments lighter than the police baton might prove useful in some circumstances where incapacitation could be prolonged by repeated impacts causing skin and/or periosteal pain. Instruments similar to a light, flexible walking stick or a long riding crop could be designed so as to cause no permanent damage if the face and anterior neck are avoided. Such an old-fashioned technique could be called incapacitation by flogging. A carefully designed variation of brass knuckles could cause periosteal pain with an openhanded slap at a subject's scalp or other bony area, and at the same time be ready to add weight to a fist blow if required.

VI. Recommendations

1. In the light of present knowledge, the outlook for non-penetrating impact as a reliable agent for incapacitation without permanent damage is poor for all impact effects except pain. It is doubtful that laboratory results in the next few years will justify a more favorable view of the possibilities of a general purpose system delivering heavy blows to the body.

2. Consider the hypothetically possible results of a general purpose concussion system shown in Table II, page 16. If similar results are acceptable as a goal, proceed with concussion system development and field testing. If such results are unacceptable, abandon development of concussion systems until laboratory demonstration of results better than those shown in Table II.

3. Insist on some documentation of biologic effectiveness and hazards of any proposed impact incapacitation technique, other than those incapacitating by superficial pain, before starting detailed hardware development programs.

4. Heavy impacts might be useful in special circumstances where the subject can be expected to be relatively still in a predetermined location and posture. For example, the space behind the pilots' seats in an airliner could be partially covered by a large piston-like movable panel in the overhead or sidewall trim. If a hijacker moved into the proper position, a pilot could trigger the 10 kilogram or heavier piston to move down or out and hit the subject at about 3 meters per second. The effects of such an impact should give the pilots a few seconds in which to apply restraints or otherwise continue incapacitation of the subject, and likelihood of permanent injury to the subject from the primary impact or any secondary impacts should be small. Similar methodology might be appropriate in other special situations where the system can be closely controlled and rapidly followed up by competent operators.

5. Projectile systems are and will probably continue to be of limited utility if safety of the subject is of any concern. Like the Remington Stinger load, they will probably remain constrained by a minimum safe range and a maximum effective range that are not too far apart.

6. A device with a range greater than that of the human knee could prove useful in incapacitating males by testicular impact. Blows delivered upward between the legs offer the possibility of highly effective incapacitation with a relatively wide margin of safety, although little scientific information is available on this technique.

7. Lightweight handheld instruments on the order of riding crops could be used in some circumstances to incapacitate by repeated applications of superficial pain. Carefully designed brass knuckles could also prove useful.

REFERENCES

1. von Gierke, H. E., "Response of the Body to Mechanical Forces," in Lectures in Aerospace Medicine, Sixth Series, USAF School of Aerospace Medicine, Brooks Air Force Base, Texas, 1967, pp 326-344. (UNCL)

2. von Gierke, H. E., "Biomechanics of Impact Injury," in Impact Acceleration Stress, Publication 977, National Academy of Sciences -- National Research Council, Washington, 1962, pp 121-122. (UNCL)

3. Stapp, J. P., "Jolt Effects of Impact on Man," in Impact Acceleration Stress, Publication 977, National Academy of Sciences -- National Research Council, Washington 1962, pp 123-130. (UNCL)

4. Williams, D., and D. Denny-Brown, "Cerebral Electrical Changes in Experimental Concussion," Brain, Vol. 64, 1941, pp 223-238. (UNCL)

5. Denny-Brown, D. and W. Ritchie Russell, "Experimental Cerebral Concussion," Brain, Vol. 64, 1941, pp 93-164. (UNCL)

6. Higgins, L. S., R. A. Schmall, C. P. Cain, et al, "The Investigation of the Parameters of Head Injury Related to Acceleration and Deceleration," AD 659 795, Headquarters, U. S. Army Medical Research and Development Command, Washington, 1967. (UNCL)

7. Clemedson, C. J., G. Hellstrom and S. Lindgren, "The Relative Tolerance of the Head, Thorax and Abdomen to Blunt Trauma," Annals of the New York Academy of Sciences, Vol. 152, Art. 1, 1968, pp 187-198. (UNCL)

8. Swearingen, J. J., "Tolerances of the Human Face to Crash Impact," AM-65-20, Federal Aviation Agency, Office of Aviation Medicine, Oklahoma City, Oklahoma, 1965. (UNCL)

9. Oxford Extra-Mural Unit, "The Wounding Power of Debris," R. C. 423, Ministry of Home Security, London, 1944. (UNCL)

10. Kleiman, A. H., "Injury to the Testes," in Encyclopedia of Sport Sciences and Medicine, Ed. L. A. Larson, The Macmillan Co., New York, 1971, p 766. (UNCL)

11. Bornheim, G., "Non-Lethal Bullet Studies," letter report SMUFA-J7000, U. S. Army Frankford Arsenal, Philadelphia, Pennsylvania, 27 November 1968. (OUO)

12.

(CONFIDENTIAL)

13.

(CONFIDENTIAL)

14. Shock Hydrodynamics, Inc., "Proposal for a Quantitative Study of Non-Lethal, Non-Penetrating Incapacitating Projectiles," Sherman Oaks, California, 1970. (UNCL)

15. Williams, L. W. and H. J. Hucek, "A Commentary on Shot-Filled Bags as a Non-Lethal Weapon for Crowd Control," Battelle Memorial Institute, Columbus, Ohio, 1970. (OUO)

16. Govons, S. R. and R. A. Merkel, "Instantaneous Postural Reaction of Cattle to Brain Concussion," Aerospace Medicine, Vol. 42, No. 4, 1971, pp 421-423. (UNCL)

17. Applegate, R., "New Riot Control Weapons," Ordnance, Vol. 49, No. 265, 1964, pp 67-70. (UNCL)

18. Brazeal, M., "The Uses of the Police Baton," in Crowd and Riot Control Schools, Ed. J. S. Kline, Governmental Research Center, Lawrence, Kansas, 1964, pp 20-24. (UNCL)