Technical Memorandum 3-76

MODELING FOR LESS-LETHAL ELECTRICAL DEVICES

Donald O. Egner
Ellsworth B. Shank

January 1976

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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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The advantages of electrical less-lethal weapons are discussed along with the general less-lethal weapon evaluation model. The basic electrical parameters of voltage, current, power and frequency are discussed. General data is developed relative to the physiological responses.

A parameter termed as no-let-go current is considered and data values are presented to provide limits for both desirable and undesirable usage effects. These effects are discussed in some detail and related to application for a 50 kilogram man. (over)

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20. Abstract (Continued)

Information required for utilization with the general less-lethal weapons evaluation model is assembled where feasible.

Finally, two existing electrical less-lethal weapons are briefly discussed and their prime characteristics noted.

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EXECUTIVE SUMMARY

Electrical less-lethal weapons offer many advantages not found with other types of less-lethal devices. Some of the advantages are: Broad spectrum of incapacitation, predictable physiological effect, controllability of dose, rapid incapacitation, etc. It should be pointed out, however, that the duration of incapacitation with the use of an electrical device is critical, in that longer durations have an increasingly associated hazard.

Electrical devices can be evaluated using the general model for the evaluation of less-lethal weapons. Some parameters for which data must be assembled for the evaluation are related to voltage, current, power and frequency. The major parameter for the determination of desirable effects is the so-called no-let-go (NLG) current. Basic data for this parameter has been gathered for certain conditions and is available. The average NLG current for men is 16 milliampere; for women, 11 milliampere (60 Hz).

A major parameter associated with the evaluation in terms of undesirable effects is minimum fibrillation current. Unfortunately, most data available is for animals rather than humans, and the human accident data is primarily impulse shocks and is not of much value. However, a reasonable estimate of a maximum nonfibrillation current is around 67 ma. This is at least three times the so-called NLG currents which would produce desirable effects. However, the trade-offs between desirable and undesirable effects have not been established in other than an average or general sense. Further work is required to treat the distributions of effects.

Some basic information has been gathered on two commerically available items, viz., the shock baton and the TASER. These data generally show that these items should be effective to some degree, and are relatively "safe." Unfortunately, the public nonacceptance of the shock baton negates its advantages. Simple tests of the TASER has not demonstrated its capabilities.

Although electrical less-lethal weapons appear to show great promise for noninjurious application, little effort has been directed toward their development or evaluation. The basic model developed for the evaluation of less-lethal weapons is applicable to electrical devices, although more basic data needs to be gathered prior to useful evaluations.

Research and development efforts should be pursued for less-lethal electrical weapons in that this approach possesses many of the desired features for less-lethal weapon application.

Good public relations are essential and must be developed for electrical less-lethal weapons along with the technical development of such items.

MODELING FOR LESS-LETHAL ELECTRICAL DEVICES

INTRODUCTION

General

The attention given to electrical less-lethal weapons by government agencies has been minimal. This is probably the result of the public attitudes on crowd control originating in events where so-called "cattle prods" were used by the police in the early civil rights demonstrations. The overall less-lethal weapons program has been influenced by this reaction to public sentiment and, as a result, very little has been accomplished in providing a viable model for evaluating electrical less-lethal devices.

It is rather strange that this particular area of less-lethal weapons has been curtailed because the information that is available tends to indicate that electrical devices have, in concept, many of the desirable features of less-lethal devices except, of course, the most critical feature of public acceptance. Figure 1 is a graphical attempt to portray the value characteristics of electrical-type weapons relative to other less-lethal weapon types.

The ideal less-lethal device should be capable of either causing an individual to flee or to produce near instantaneous incapacitation of the individual. It should have no incapacitating effect beyond the time required by the control force in the particular situation and should be as safe as can be devised both for the person subjected to the device's effect and to the control officer disseminating the effect. In concept, the electrical device can achieve all of these requirements—whether or not such characteristics can be achieved in practice is unknown since no public funding for the development of such items has been made. The characteristics of two electrical less-lethal devices (developed by the private sector) are discussed briefly below but, again, due to lack of emphasis, very little test data on these items is available.

In general, the performance and suitability of electric shock for incapacitation of offenders may be affected by several variables which characterize the incapacitating current. The more important electrical parameters are voltage, current, power (or energy) and frequency. The spectrum of physical and physiological effects produced by the variations of voltage, current and frequency is probably familiar to many readers: the tingle of a mild electric shock of low amperage, the appearance of a high-voltage arc discharge, the accidental burn from 110 volt, 60-Hertz "house current" or the painful shock from the high voltage of an automobile ignition system.

In terms of incapacitation and biological effects on living systems, current—not voltage—is the most important variable of electricity. The frequency of the current is also a factor in determining the deleterious effects of electric current, especially with regard to the sensitivity of the human heart.

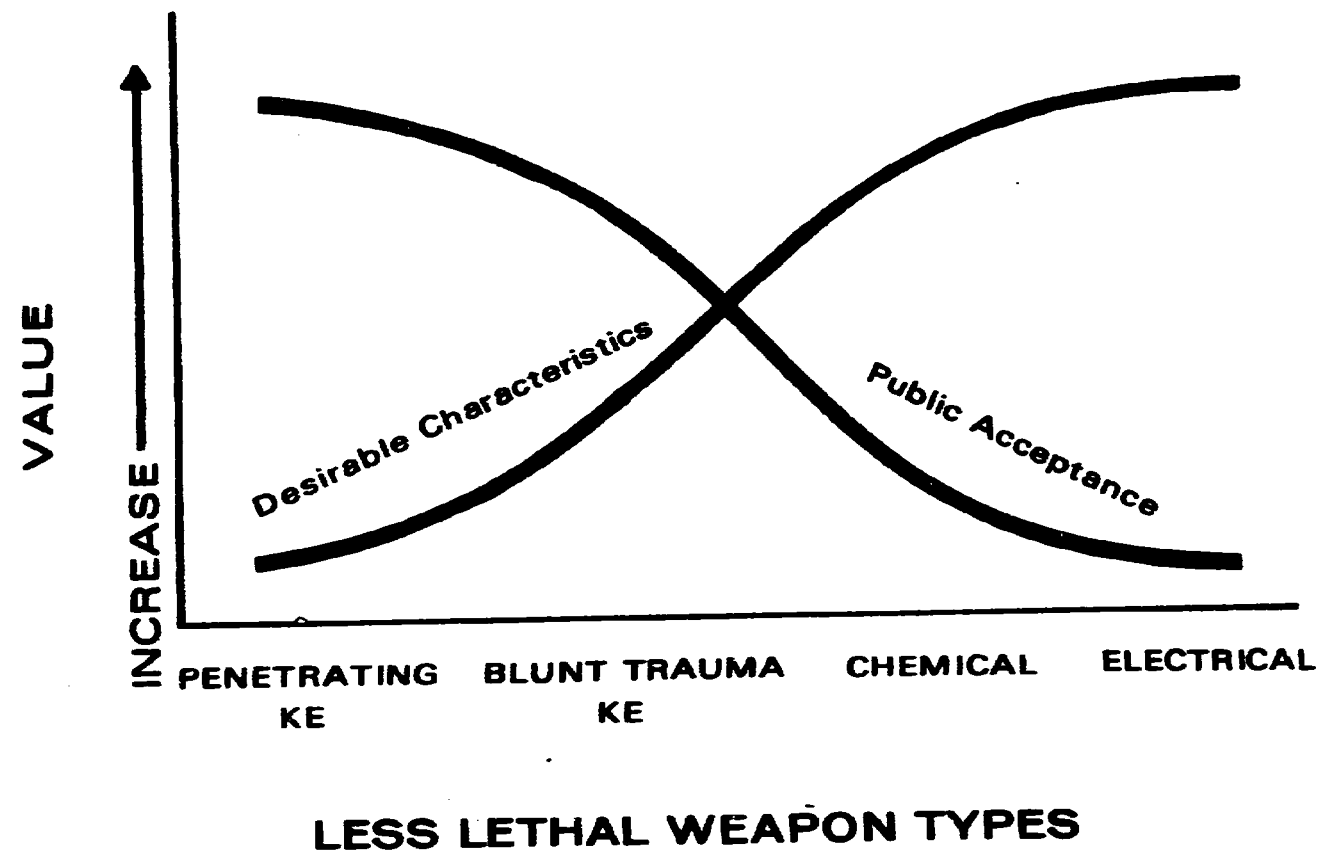

Fig. 1. Value of weapon types in terms of desirable characteristics and public acceptance.

Thus an unusual aspect of electrical less-lethal devices is that a considerable body of information (though far from complete) is available on the critical aspects of safety and incapacitating effect. Even though this information is incomplete, it is far more definitive and specific than comparable information on kinetic energy less-lethal devices and possibly superior to the critical information available on chemical less-lethal devices.

In the evaluation of any less-lethal device, the critical problem is the identification of valid, measurable, quantitative criteria for effectiveness (desirable effect) and safety (undesirable effect—or "less-lethalism"). The basic product of this report is the presentation of information available for these two criteria.

Review of Prior Modeling Work

Very little has been done in the development of evaluation techniques for less-lethal electrical devices by the scientific community. However, the therapeutic value of electrical shock in the treatment of certain mental disorders and shock treatment as an implement in the training of laboratory animals for discriminatory tasks are well known. Aside from the limited pilot testing of products by manufactureres of the electrical devices for marketing appraisal, the testing of electrical devices as they relate to less-lethal weaponry has been largely lacking. Some data exists on electrical shock but not in a form which would be applicable to evaluation of less-lethal weapons.

The problem in modeling for the electrical devices is getting the quantitative performance information to relate logically to a measure of effectiveness. Since very little has been done previously in evaluating electrical devices (one trained monkey test of TASER[1] effectiveness), one is not bound as to the way data has been taken in the past.

Under the overall Less-Lethal Weapon Evaluation Program a general method or technique as developed for evaluating various types of less-lethal weapons. This first evaluation model was ilt around the blunt-trauma-type less-lethal weapon. Although the original methodology rtains particularly to blunt-trauma devices, the general concepts and techniques can be dapted and extended to include the electrical devices.

The overall evaluation technique includes the use of standard scenarios, theoretical and experimental determination of weapon performance data, and determination of the physiological and nonphysiological effects, both from a desirable and undesirable effectiveness standpoint. The general method described as follows combines the above elements into a simple measure of effectiveness or index for comparison.

Essentially, the evaluation procedure presented consists of five key elements as follows:

- Scenario Selection
- Weapon/Device Performance Data

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[1]TASER, a commercial electrical less-lethal weapon is discussed in some detail at a later point in the text.

- Physiological Effects Data
- Nonphysiological ("Other") Effects Data
- Model Application for a Relative Merit Index

DISCUSSION

The Model

The model for electrical devices follows the previously developed general evaluation model as described by the above-mentioned model elements. The relationships of these elements to one another provide an evaluation procedure. These relationships are shown generally in Figure 2.

To develop the model for the electrical devices, a detailed set of quantitative relations which identify the units of all intermediate parameters and which give a relative measure of value as a function of device performance and use conditions is required. As an expedient, an intensive survey was conducted of the quantitative data which presently exists on the relation between electrical stimuli and physiological response.

The precise procedure for calculating a numerical index of electrical weapons effects and hazards is as follows:

A particular scenario is chosen from among those developed and described in US Army Human Engineering Laboratory Report "Standard Scenarios for the Less-Lethal Weapons Evaluation Model." It is significant to note that the scenario provides a constant basis for weapon evaluation. Moreover, the choice of scenario determines certain quantitative parameters such as time and geometric relations, but most importantly the chosen scenario defines the undesirable and desirable effects to be used in the particular evaluation. The candidate less-lethal weapon is selected and its characteristics identified. Once the scenario is chosen and the specific weapon characteristics identified, the terminal parameters values are calculated and the pertinent data re-extracted from the data banks.

The data extracted from the data banks are the probabilities of effects given a hit on the target. The determination of these are a primary problem in the development of the "electrical" model. However, once this information is obtained it is appropriately combined with the information on weapon dispersion and target geometry to provide a final measure of undesirable and desirable effects. This latter data bank has not been established for electrical devices to date, and thus prevents one from performing a full evaluation using the model.

The Data

General - Available Data

As previously stated, in order to utilize the model, quantitative data on the relation between electrical stimuli and physiological response is required. These responses are related to the damage mechanisms. It is desirable to present the available data in a form which gives insights

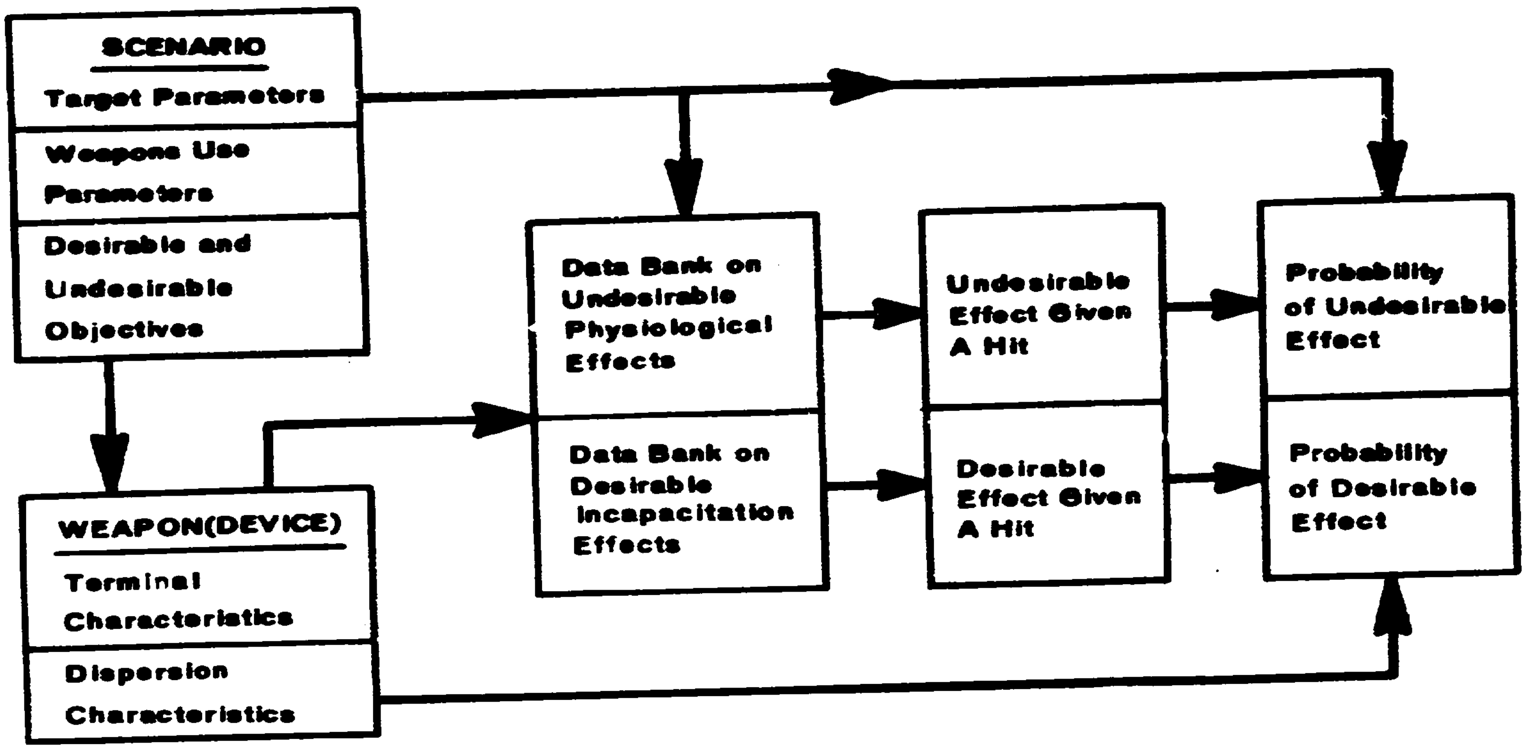

Fig. 2. A general concept of an evaluation procedure for less-lethal weapons.

into just how effective and safe electrical current might be when used as a less-lethal-damage mechanism. This data is best presented in terms of the voltage, current, frequency, and shock duration values which have been imposed on human volunteers and the resultant physiological effects.

In utilizing electric current as a less-lethal-damage mechanism, the basic objective is to produce disabling spasms of skeletal muscles in the target, subject to the following constraints:

- The shock should not produce cardiac arrest.
- The shock should be nonlethal to a healthy adult.
- The requirement for immediate post-shock medical care should be avoided.
- Burns, post-shock paralysis, or mechanical injury should be minimized.
- Long-term after-effects such as permanent brain or neuromuscular damage must be avoided.

While one is interested in the debilitating effects of electrical shock, virtually all the available literature is directed toward the minimization or elimination of shock hazards. Extant reports describe in detail maximum safe levels, currents, frequencies and shock durations thought to induce ventricular fibrillation, required response times of ground fault detectors, and so forth. Because of this, the data utilized in this effort is based on a single source: the work of Charles F. Dalziel at the University of California at Berkeley. From 1932 until 1968, Mr. Dalziel conducted research and compiled the results of other investigators on the various phenomena associated with electrical shock. His work is presented in several publications of the Institute of Electrical and Electronics Engineers (IEEE) and Atomic Energy Commission safety bulletins.

Mechanisms of Effects

As it relates to the incapacitation problem, electric current has only three significant effects on human tissues:

a. Depolarization of nerve and muscle tissue, causing the "firing" of nerve or brain cells and contraction of muscle fibers. Depolarization causes the subjective tingle, involuntary muscular contractions and several other side-effects of an electric shock.

b. Change in sensitivity of certain irritable tissues, such as increased heart irritability and sensitivity to ventricular fibrillation. Fibrillation is a major threat to life which may ensue when moderate electrical currents pass through the heart. Death can follow because a fibrillating heart cannot pump blood. However, cardic arrest may be produced without ventricular fibrillation.

c. Heating, to the point of coagulation and burning if current flow is large enough or concentrated in a small area.

All three of the above effects could contribute to the pain of a severe shock, although a large part may be pain due to muscle spasm. Current of sufficient magnitude will cause painful involuntary contraction of muscles as the currents pass through an extremity. The motion made by the extremity as the muscles contract will depend upon: (1) the muscle groups stimulated, and (2) the relative strengths of contraction of the various muscle groups. A person "thrown" or "knocked down" by electric shock has been moved by his own muscle contractions rather than any direct propulsive effect of the current. Relatively weak movements caused by small currents can be overcome by voluntary muscle control, especially in large powerful people. A "no-let-go" (NLG) current threshold can be determined by measuring progressively larger currents flowing through a person's arm from a electrode grasped in his hand, up to the current at which he can no longer voluntarily release the electrode with the current flowing. The NLG threshold for adults is in the 6 to 30 ma range for 60 Hz AC. Current values will be similar for other AC frequencies in the 10 to 1,000 Hz range, but DC currents would have to be about five times as large for similar effect.

Physiological Effects Thresholds

a. Alternating Current "No-Let-Go" (NLG) Thresholds

(1) Current

NLG current(2) was determined for 134 men and 28 women by placing one of the subject's hands or feet on a brass plate and completing a 60-cycle AC circuit through a No. 6 copper wire held in the subject's opposite hand. Amperage was increased until the subject could not let go of the copper wire on command. It was noted that motivation has a significant effect on subjects' performance, with friendly wagers between subjects resulting in an increase of up to 6 ma in NLG threshold. One highly motivated male subject tolerated 26 ma, but he was informally observed to have had muscle cramps for at least a week following the trial. It was also noted that physiological development of the arms and wrists was positively correlated with NLG threshold.

NLG threshold (1) was established at 15.9 ma for men and 10.5 for women; these points represented the 50th percentile tolerance level in each case. The distribution of NLG current thresholds is normally distributed.

Dalziel remarked on several effects associated with the determination of 60-cycle NLG threshold. The first of these was that the higher current values (18-22 ma) were sufficient to stop breathing during the time the current flowed across the chest. This was attributed to muscle paralysis rather than to inhibition of the respiratory center. His other major observation is contained in the following quote:

> "Currents only slightly in excess of one's NLG current value are very painful, frightening and hard to endure for even a short time. Failure to interrupt the current promptly is accompanied by a rapid decrease in muscular strength due to the pain and fatigue associated with the accompanying severe involuntary muscular contractions, and it would be expected that the let-go ability would decrease rapidly with the duration of contact. Prolonged exposure to currents only slightly in excess of a person's NLG limit may produce exhaustion, asphysia, collapse and unconsciousness followed by death"(3)

(2) Voltage

NLG voltages are relatively meaningless for low voltage circuits because of the unpredictable nature of skin and contact resistance. Table 1 shows the representative skin

TABLE 1

Representative Skin Resistance Values For Humans[a]

Contact Area	Resistance (OHMS)	Remarks
Temple to temple	100	Measured during shock therapy
Hand to hand	1570-4430	Electrodes wet with salt solution
Right hand to both feet	1230-2150	Subject standing in 3/4" salt water bath

[a]These data based on conversations with a cardiologist and medical personnel.

resistance values. Whether or not a subject lets go depends on his particular electrical resistance characteristics (thought to vary widely among individuals) and the degree of discomfort he is willing to tolerate.

For kilovolt circuits, body skin and contact resistances break down immediately and the target receives a very high current.

Despite these ambiguitities, tests were run to determine NLG voltage for 60-cycle AC. These tests resulted in a hand to hand value of 20.3 volts, and 10 volts for a path from one hand to both feet ankle deep in salt water (3). Since the original report on this research could not be obtained, the current used in this test is not known.

(3) Frequency

Tests were conducted (2) on smaller groups of men to determine the effect of frequency on NLG current. Sinusoidal waves having frequencies from 5 to 1,000 Hz were used.

It is noted from these data that NLG current is very low in the 50-60 Hz range. This indicates that these frequencies evoke more pronounced responses from human subjects than from test animals. Also it should be noted that these are the commercial frequencies used throughout the world.

b. Direct Current NLG Thresholds

Direct current produces internal heating sensations rather than muscle contractions. However, sudden changes in current magnitude produce powerful contractions, and interruption of the current produces a severe shock(3). Since tolerance to DC is more a function of the subject's willingness rather than his inability to release the wire, results are rather ambiguous. However, a probable average DC NLG release current was estimated to be 76 ma.

c. Impulse Current Hazards

Impulse shocks are high voltage, high direct current, short duration episodes. The effects on man vary from headaches to severe burns and from paralysis and mental dysfunction to no discernible damage. Table 2 summaries data from reference(4), which presents a collection of data on impulse current accidents from a number of countries. These particular accidents are included because sufficient information was obtainable to analyze the circuit and quantify the shocks received by the victims. It was noted that there was little predictability of the nature of injuries as a function of shock intensity and duration to the individual. Table 2 also indicates the extreme range of values under which these nonfatal accidents occurred.

Reference 4 also presents the results of impulse tests on sheep and pigs. Weight of the test animals was presented, as well as the energy (in wattseconds) actually received. The effects of these shocks were noted, and equivalent shock energies were computed for a 70 kg. man. Again, there was considerable variability in the results.

A little understood phenomenom associated with severe impulse shock is the development in the victim of "acute brain syndrome."(5) Acute brain syndrome is not a diagnosis of exclusion, i.e., it is not a name applied when nothing else fits. It is noninfectious brain damage having an organic basis; it can be precipitated by drug or alcohol abuse, kerosene or gasoline poisoning, electrical shock, or a number of other events.

TABLE 2

Summary of Calculated Electric Shock Quantities Received by Victims

Time Constant Limits Microseconds	Voltage Limits Kilovolts	Alternating Current Ampers	Quantity Milli-Coulombs	Energy Watt-Seconds
0.1 to 35,000	2 to 960	4 to 1,600	1 to 140	9 to 25,000

NOTE: All victims survived but apparently had various degrees of incapacitation lasting from hours to days.

The syndrome is characterized by the rapid onset of mental deterioration—loss of reasoning ability, total inability to make decisions, disorientation, etc. Psychotic episodes may occur, including fugue, amnesia, irrational acts of violence, paranoia, and depression. Symptoms last several months, during which time the victim is dependent upon others for his maintenance. It is not known what level of shock produces the syndrome, but it is known that the current path need not be through the head. High energy field effects must not be ruled out, however, since unsubstantiated reports have been collected which indicate similar symptoms have resulted from the application of a 50-kilogauss pulsed magnetic field.

d. Fibrillation Thresholds

The probability of electrically inducing fibrillation is a function of shock duration, body weight of the victim, current delivered, and phase of the cardiac cycle. Since the application toward which this study is directed does not allow for close control of experimental subjects, the last of these variables should be ignored, except for use in determining maximum acceptable nonfibrillating shock.

Because ventricular fibrillation in man does not spontaneously cease, experimental data is confined to animals—primarily dogs, pigs, calves, and sheep. The following sections will cover the variables listed above and present an equation for determining maximum nonfibrillating shock in terms of those variables.

(1) Shock Duration

Data on this variable is available from several sources, all of which are summarized in Dalziel and Lee(2). Unfortunately, the data applies to dogs only. The results presented in reference 2 are summarized in Table 3.

(2) Body Weight

Table 4 shows minimum fibrillating current as a function of body weight based on data from 45 dogs; using 3-second shocks. A correlation coefficient of $r = +0.74$ between current and weight was found for these data. Similar data for dogs, as well as for 25 sheep, 11 calves, and 9 pigs is contained in reference 2. The regression line for these data indicates a coefficient $r = +0.84$. From these cases it can be concluded that minimum current required to produce fibrillation is proportional to body weight for larger animals as well as dogs. It is therefore considered justifiable to assume, in the absence of other data, that these curves apply to man as well as other animals. If a very conservative value of 50 kg (110 lb) is taken for the average weight of an adult homo sapiens, the reference data indicates a maximum nonfibrillating current (at the 0.5 percentile level) of 67 ma and a minimum fibrillating current of 107 ma. Comparison of this information to the NLG current thresholds discussed previously indicates that for 3-second shocks(2), an individual's NLG current could be tripled without incurring significant danger of inducing ventricular fibrillation.

4. Electrical Applications

a. Electrocution Equation

Examination of data indicates that the relationship between fibrillating current and shock duration may be represented by an equation of the form

$$I = K/\sqrt{T}$$

TABLE 3

Approximate Minimum Fibrillating Currents
Versus Shock Duration For Dogs

Shock Duration Seconds	Minimum Fibrillating Currents[a] Milliamperes (rms)
0.01	800
0.1	200
1.0	60
10.0	20

[a]These are estimated from data presented by Dalziel and Lee (2).

TABLE 4

Summary of Minimum Fibrillating Currents
Versus Body Weight for Dogs
(3-Second Shocks)

Body Weight Kilograms	Minimum Fibrillating Currents[a] Milliamperes
10	30
20	100
30	135

[a]These are estimated from data presented by Dalziel and Lee (2).

where I = current in ma
K = electrocution constant
T = shock duration in seconds

The constant K is obtained from the data of Dalziel and Lee for a body weight of 50 kg. For 3-second shocks, the results are as follows:

$$K = 107\sqrt{3} = 185.3 = \text{minimum fibrillating}$$

$$K = 67\sqrt{3} = 116.0 = \text{maximum nonfibrillating}$$

Inserting the desired value of T into the equation allows estimation of current levels which should not cause ventricular fibrillation for any shock duration from 8.3 ms to 5 seconds. No data exists for shocks outside this time envelope. However, shocks shorter than 8.3 ms (one half wave of 60 cycle AC) should probably be classified as impulse shocks, while it has been suggested that from 5 seconds to 20 or 30 seconds (3 to 18 cycles) the fibrillation threshold remains fairly steady, with perhaps a slight drop (2).

b. Alernative Techniques for Incapacitation

From time-to-time, the idea of inducing temporary cardiac arrest via electric shock produced by a less-lethal weapon is considered.

Discussions on this topic with a cardiologist (5) produced some interesting observations, as follows:

In hospitals, with teams of surgeons attending a normally healthy patient undergoing cardiac catharization, if cardiac arrest occurs, only about 20 percent of the patients are successfully resuscitated. Thus, the irreversible effect is high, i.e., 80 percent. When people with diseased hearts suffer cardiac arrest during surgery $\leq$ 10 percent survive.

In addition to the above, it is believed that a person forced into a cardiac arrest situation would still have time to perform physical acts, prior to becoming unconscious.

In treating certain cardiac conditions, 25 to 400 watt seconds of electrical energy is routinely applied to the skin of patients (one probe to each side of the chest). The normal energy here is 200 watt seconds. The objective is to depolarize the heart for a few seconds, after which it converts to normal rhythm, hopefully permanently.

If this approach was used as a less-lethal weapon, one would apply ~ 200 watt seconds of electrical energy across the chest of the target. This would depolarize his heart for a few seconds (it would temporarily stop beating normally, but this would not constitute a true cardiac arrest). Blood flow to the brain would be interrupted and the target would become unconscious in a matter of seconds as indicated in Table 5.

TABLE 5

Estimated Response Times for Subject to Become Unconscious Due to Heart Depolarizations

Target Posture	Response Time (Sec.)
Standing	4-8
Sitting	6-10
Prone	12-15

c. Burn Damage

Electric burns can be produced both by the passage of current through tissues and by arcing between the energized conductor and the body. Such burns are slow to heal but rarely become infected. However, burn lesions offer very low resistance to electric current, the result being greatly increased current flow through the burn site. In connection with these phenomena, Dalziel(2) points out that currents of the NLG level are more than sufficient to cause deep burns, particularly if there is an air gap between the conductor and victim. He also remarks that currents almost too small to measure produce severe pain when they flow in an open wound.

EXISTENT LESS-LETHAL ELECTRICAL WEAPONS

General

Although many concepts for electrical devices have been proposed, only two types in general have been found in the U.S. market. The first is the standard Shock Baton, while the second (TASER), utilized a launch system to project wire leads to the target, thus giving a greater stand-off capability than the night-stick type of electrical shocker.[2] Table 6 gives the characteristics of the less-lethal electrical weapons.

Shock Baton

A shock baton was utilized in some simple tests; however, no effort was made to evaluate the device using the proposed general evaluation model. Although in reality this was due to the limitations of the study effort, it was also felt that such an evaluation would be futile in light of the poor public acceptance brought on by the manner in which it was publicized during the civil rights demonstrations. This is extremely unfortunate since electrical devices appear to hold the greatest promise for effective and safe less-lethal weapons. It is thus obvious that the primary break through for this type of weapon is not necessarily in the technical field, but rather in public relations providing factual evidence to the public that the rejection of this type of weapon has led to greater hazards to the public, and less-effective means of law enforcement to the police.

TASER

Although some accuracy type tests were originally planned to provide input data for the evaluation model, these were cancelled due to various reasons. However, some very elementary tests had been conducted(6) to determine the desired effectiveness which might be due to muscle tetany. An analysis of the data(7) presented in an unpublished memo concludes that under the conditions of the test the TASER had no appreciable effect on the monkey being able to perform his assigned task. One is cautioned, however, that these were very limited tests and conditions of testing, of course, affect the conclusions drawn from the tests.

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[2] These electric shock type devices are also found in gloves and jackets.

TABLE 6

Characteristics of Existent Less-Lethal Electrical Weapons

TYPE	POWER SOURCE	OPERATING VOLTAGE (kv)	FREQUENCY (cps)	PULSE WIDTH (milliseconds)	CURRENT PER PULSE (milliamperes)
SHOCK BATON[a]	Four 1.5v cells	4	= 143	.5	.6
TASER[b]	N/A	30 to 60	10	Not available	10

[a]All values noted measured from sample unit.

[b]All values noted cited in manufacturer's literature.

CONCLUSIONS

General

Although electrical less-lethal weapons appear to show great promise for noninjurious application, little effort has been directed toward their development or evaluation. The basic model developed for the evaluation of less-lethal weapons is applicable to electrical devices, although more basic data needs to be gathered prior to useful evaluations.

Specific

An "average" man will be unable to release a wire conducting 15 ma (60 cycle AC) through his body to ground. A highly motivated man has managed to release a wire carrying 25 ma.

Currents from 18 to 11 ma are sufficient to paralyze muscles of respiration for the duration of the shock.

Prolonged exposure to currents just in excess of NLG current may result in exhaustion, asphyxiation and death.

Currents of the magnitudes mentioned above are sufficient to produce serious burns under certain conditions.

NLG current is minimized when AC frequency is held between 10 and 100 Hz.

Direct current results in internal heating effects rather than muscle contractions. However, circuit interruption or gross current variation results in severe muscle contraction. Maximum voluntarily accepted DC release current is on the order of 76 ma.

Subjecting an individual to 3 times his let-go current should not, in most cases, result in ventricular fibrillation.

Human susceptibility to surge current is highly variable, with damage as minor as startle effects and as major as severe burns, paralysis, and long-term mental deterioration.

Cardiac arrest as a mechanism of effectiveness is not only very risky and dangerous but most likely will not produce the desired effects in the required time frames.

Although electrical energy can be used to depolarize and render a target unconscious, the response is not instantaneous.

RECOMMENDATIONS

Research and development efforts should be pursued for less-lethal electrical weapons in that this approach possesses many of the desired features for less-lethal weapon application.

Good public relations are essential and must be developed for electrical less-lethal weapons along with the technical development of such items.

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