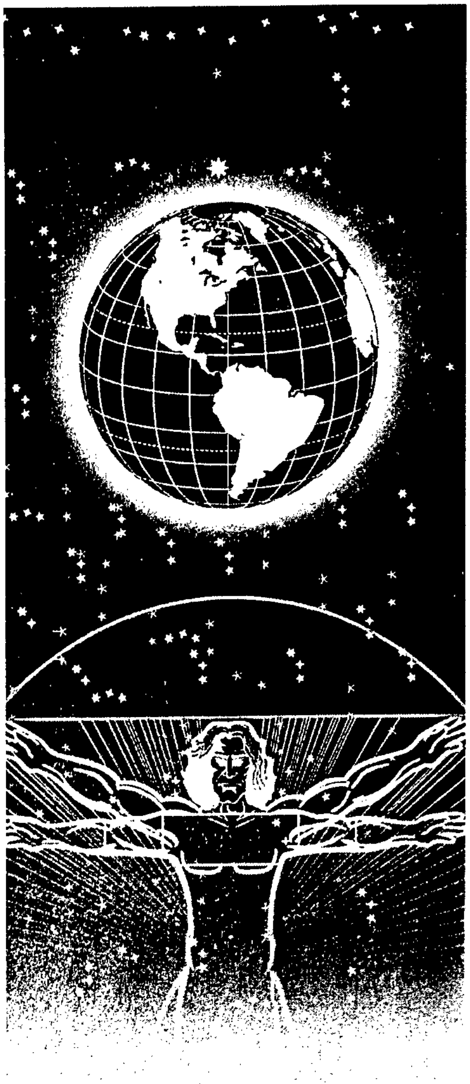
AFRL-HE-BR-TR-2003-0089



UNITED STATES AIR FORCE RESEARCH LABORATORY

AN EVALUATION OF THE ELECTRICAL PROPERTIES AND BIO-BEHAVIORAL EFFECTS OF FOUR COMMERCIALLY AVAILABLE TASERS AND THE JAYCOR STICKY SHOCKER

Clifford Sherry
Carroll Brown
Charles Beason
Thomas Dayton
James Ross

Veridian Engineering
9601 McAllister Freeway, Ste 1165
San Antonio, TX 78216

James Jauchem
Leland Johnson
Charles Kuhnel

HUMAN EFFECTIVENESS DIRECTORATE
DIRECTED ENERGY BIOEFFECTS DIVISION
RADIO FREQUENCY RADIATION BRANCH
8262 HAWKS ROAD
Brooks City-Base, TX 78235-5147

June 2003

NOTICES

This report is published in the interest of scientific and technical information exchange and does not constitute approval or disapproval of its ideas or findings.

This report is published as received and has not been edited by the publication staff of the Air Force Research Laboratory.

Using Government drawings, specifications, or other data included in this document for any purpose other than Government-related procurement does not in any way obligate the US Government. The fact that the Government formulated or supplied the drawings, specifications, or other data, does not license the holder or any other person or corporation, or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

The Office of Public Affairs has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

James R. Jauchem

JAMES R. JAUCHEM, Ph.D.
Project Monitor

RMiller

RICHARD L. MILLER, Ph.D.
Chief, Directed Energy Bioeffects Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-01-0188

EPORT DATE *(DD-MM-YYYY)*
ne 2003

2. REPORT TYPE
Interim

3. DATES COVERED *(From - To)*
Jan 2002-Jun 2003

ITLE AND SUBTITLE
ı Evaluation of the Electrical Properties and Bio-behavioral Effects of Four ›mmercially Available TASERs and the Jaycor Sticky Shocker

5a. CONTRACT NUMBER
F41624-96-C-9009

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62202F

UTHORS
ıerry, Clifford J., Brown, G. Carroll, Beason, Charles W., Jauchem, James , Dayton, Thomas E., Ross, James A., Johnson, Leland R., Kuhnel, Charles , Fines, David A., and Theis, Clarence F.

5d. PROJECT NUMBER
7757

5e. TASK NUMBER
B3

5f. WORK UNIT NUMBER
17

ERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
 əridian Engineering
ı01 McAllister Freeway, Suite 1165
ın Antonio, TX 78216

8. PERFORMING ORGANIZATION REPORT NUMBER

PONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
ir Force Research Laboratory (AFMC)
ıman Effectiveness Directorate
irected Energy Bioeffects Division, Radio Frequency Radiation Branch
:62 Hawks Road
:ooks City-Base, TX 78235-5147

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-HE-BR-TR-2003-0089

DISTRIBUTION/AVAILABILITY STATEMENT
pproved for public release.

SUPPLEMENTARY NOTES
FRL Technical Monitor: James R. Jauchem, (210) 536-3572

ABSTRACT
ıe TASER is a device that propels two darts into a subject and transmits short pulses of electric current through wires, causing involuntary ıscle contractions that incapacitate. Four commercially available TASERs (Tasertron's Model TE86 and Model 95HP; TASER International's odel 34000 "Air TASER" and Model 44000 M26 "Advanced TASER") and a prototype self-contained TASER-like device (Jaycor's "Sticky ıocker") were tested for effectiveness. The output voltage of each was obtained using four different voltage divider dummy loads: 100, 1000, ı00, and 10,000 ohms. Eleven minipigs (*Sus scrofa*) were exposed to the output of each device for 15 sec, with a minimum rest period of 45 hrs tween succeeding exposures. All of the devices caused most animals to run in circles. These swine were able to maintain posture and to jump. ıythmic contractions of the thorax and abdominal muscles were also observed. Only one device, the TASER International Model 44000 M26 ḍvanced TASER, caused a loss of posture (7 of 11 animals). Two of the 7 were able to regain posture while being tasered. The relative fectiveness of the various devices appeared to be related to total charge flux, with the M26 Advanced TASER having the largest value by far. aximizing the total charge flux output from a TASER should be the basis for any program designed to increase the device's effectiveness.

SUBJECT TERMS
ASER, Electric Current, Electroshock, Muscle Contraction, Animal Behavior, Non-Lethal

SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
REPORT	b. ABSTRACT	c. THIS PAGE			James R. Jauchem
					19B. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	30	(210) 536-3572

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

OBJECTIVE

There is a need in the law enforcement and correctional, as well as in the military communities for a non-lethal weapon that will safely incapacitate an aggressive, hostile individual without causing acute or long-term injury. The definition of incapacitation derived by the U.S. Marine Corps Joint Non-Lethal Weapons Directorate's Incapacitation to Personnel Concept Exploration Phase program is "to deprive the targeted individual or group the ability to perform desired/intended tasks or functions for a specific period of time, allowing for the individual or group to be controlled by the employing force. Effects produced should be temporary and reversible (physiological, physical or psychological)."

In an inter-agency agreement (29 September 2000), the National Institute of Justice tasked the U.S. Air Force Laboratory (AFRL) to develop a rigorous, repeatable diagnostic system to define the physical parameters of the TASER and to allow the devices from different manufacturers to be compared and contrasted. AFRL was also tasked to determine the bio-behavioral effects of TASERs and to determine if they could be used to safely incapacitate an individual.

BACKGROUND

The TASER (Thomas A. Swift Electric Rifle) is a man-in-the-loop, operator-controlled, standoff device that propels two darts into a subject and transmits short pulses of electric current through wires attached to the darts into the subject causing involuntary muscle contractions that incapacitate. The TASER was invented by John H. Cover and patented in 1974 (U. S. Patent 3803463). This patent describes a number of different ways to generate short-duration, high-voltage, low-current pulses. Currently two companies utilize the patent or a derivation of the patent to manufacture a number of different models of the TASER. These companies are Tasertron[1] (Corona, CA) and TASER® International[2] (Scottsdale, AZ). Jaycor[3] (San Diego, CA) produces a self-contained TASER-like device using a circuit similar to that used in other TASERs, which they call the Sticky Shocker. This device is not currently commercially available.

Recently, the TASER® International Advanced TASER® M26 Electro-Muscular Disrupter (EMD) had been selected to be placed in the cockpit of United Airlines planes[4]. However, this may no longer be the case, as the Bush Administration dropped its opposition to allowing firearms to be carried in the cockpit, and was followed shortly by approval in the US Senate[5].

In videotapes of TASER exposures under field conditions or during demonstrations, the subject typically falls to the ground and experiences rhythmic tonic muscle contractions. The mechanism for this loss of posture and muscle contractions has not been fully described in the scientific literature, and is likely due to the amount of current flow from the TASER during a single TASER pulse, combined with a rapid repetition of the pulses. TASER® International reported that anesthetized animals showed minimal physical response when stimulated with earlier versions of their TASER, suggesting that these stun systems were not affecting the motor nerves and muscles as much as previously thought. TASER® International reported that the newer, higher power advanced EMD functions by acting on the muscle efferent nerves causing involuntary muscle contractions.

---

[1] Tasertron TASER® utilizes a pyrotechnic primer to launch the darts, under the definition of "firearm" in section 4181 of the Internal Revenue Code (26 CFR 48.4181-2) and the Gun Control Act of 1968 (18 USC 921), the Bureau of Alcohol, Tobacco and Firearms declared that the Tasertron TASER® was a firearm on March 18, 1976.

[2] TASER® International developed a TASER® that utilizes compressed nitrogen, air or other non-pyrotechnic methods. By the definition above, these devices would not be firearms.

[3] Jaycor Sticky Shocker is self-contained. Once the Sticky Shocker electrodes attach to the subject, or the subject's clothing, the current is turned on and continues until the Sticky Shocker is removed or until its battery runs down, which ever occurs first.

[4] Carpenter, D. "Airline seeking stun guns in cockpit." Boston Globe , Friday, November 16, 2001, Third Edition,: National/Foreign Section, Page A29

[5] "Bush to OK Guns for Airline Pilots." Leslie Miller, Associated Press story, *Washington Post* web site, 5 Sept 2002, http://www.washingtonpost.com/wp-dyn/articles/A42504-2002Sep5.html

Evaluation of the peer-reviewed open literature[6] indicates the body of objective scientific research data is very limited on: 1) the mechanism of action, 2) the efficacy, 3) the safety, and 4) the acute and long-term effects of these devices. Most of the studies in the refereed literature deal with post-exposure clinical evaluations or reviews. Both TASER manufacturers have produced studies and databases that are available from their websites or other forums.

BASIS FOR THE DESIGN OF TASERS

The objective of a TASER is to temporarily disable or incapacitate an individual. This is achieved by propelling two darts into a subject, and transmitting short pulses of electric current through wires attached to the darts. The current from a single pulse is intended to cause an involuntary muscle contraction. The amount of current that is delivered to the body and the time period of current delivery determine when an involuntary muscle contraction will occur. The amount of current and duration also determines if an untoward effect, such as ventricular fibrillation, will occur. By repetitively pulsing the current at a fast enough rate, the muscle will exhibit tetanus, thus causing the subject to become incapacitated. The frequency at which a TASER is pulsed and the voltage of each pulse are determined by the electrical design of a TASER.

Thus, a TASER should be designed to produce current in a single pulse that is sufficient to cause involuntary muscle contraction without causing an untoward effect, such as ventricular fibrillation. Additionally, the pulses should be repeated at a rate that is sufficient to cause muscles to exhibit tetanus.

The current flow into the body is determined by the impedance[7] of the tissue between the TASER's attachment points and the voltage applied by the TASER. The primary variable affecting the current in the body that is not under the control of the TASER designer is impedance. Tissue is anisotropic (i.e., its impedance changes with direction of measurement). Therefore, variation in the placement of darts will introduce variability in effectiveness of the TASER. Taylor (1985) found that the average impedance between the left hand and the left foot when measured through the skin with good electrical contact is 516 ohms (standard deviation 55 ohms). Taylor (1985) also found the impedance between the shoulder and the thigh (the typical points of attachment of the TASER darts, when the TASER is fired at a human under field conditions) is approximately 50 ohms.

---

[6] This literature review is based on documents identified by a search of MedLine 1966-2001, Agricola, Bio Business, Biological Abstracts, the Patent Bibliographic Database, NTIS.

[7] Impedance (Z) is a measure of the total opposition to current flow in an alternating current circuit and is made up of two components, ohmic resistance (R) and reactance [X (opposition to the flow of alternating current caused by the inductance and capacitance)] and is usually represented in complex notation as $Z = R + iX$.

When good electrical contact is not made between the TASER barbs and the tissue underlying the skin, the electrical conducting properties of human skin become very important. Electrical conducting properties of human skin can vary significantly, possibly affecting both effectiveness and risks. Dawalibi et al. (1990) report that, according to ANSI/IEEE Standard 80[8], the nominal whole body (arm, legs, and trunk) resistance is 1000 ohms. Normal, moist skin has a resistance of about 1000 ohms (Zarowitz and Pilla, 1989; O'Brien, 1991; Smith, 1992; Yamamoto, 1994) and is affected by a variety of parameters such as blood flow and total body water (Liang and Norris, 1993), as well as the surface area of contact, pressure of contact, surface moisture, or whether the skin is cut or bruised (Robinson et al., 1990). The resistance of dry, scaly skin can be as high as 300,000 ohms. Skin resistance decreases with increasing frequency of the stimulus (O'Brien, 1991).

Based on an evaluation of the refereed literature, literature supplied by the manufacturers of TASERs, and the experiments reported above, it is not clear if the TASER effect is due to action on nerve fibers (alpha or gamma), the neuromuscular junction, muscle fibers, or some combination of the three. Alon (1991) reported that peripheral nerves contain fibers of different diameters; large fibers require the shortest pulse duration and stimulus amplitude to be fired; and small fibers require a higher stimulus amplitude and longer duration. The large fibers typically carry afferent sensory stimuli; the smallest carry afferent painful stimuli. The intermediate fibers carry efferent motor impulses; those innervating slow twitch muscle fibers are smaller than those innervating fast twitch muscle fibers. Urbscheit (1991) reports that slow twitch muscle fibers are most common in the large anti-gravity muscles that are involved in maintaining posture. Slow twitch fibers have a twitch time of about 75 ms. The critical fusion frequency to develop a tetanic contraction is about 13-15 pulses/sec. Fast twitch fibers are typically found in muscles that make rapid, precise, learned movements. They have a twitch time of about 40 ms and their critical fusion frequency is about 40 pulses/sec.

SAFETY ASSESSMENT

The safety of the original TASER was evaluated for the U.S. Consumer Product Safety Commission by Bernstein (Zylich, 1976). This evaluation was based on theoretical analysis rather than experiments on animals or humans. Bernstein (1991) compared the output of the TASER to that obtained from an electric fence controller as described in the Underwriters Laboratories (UL) Standard For Safety Number 69, "Electric Fence Controller" (see also the Underwriters Laboratory Bulletin of Research #14). He felt that an electric fence provided a good model of allowable, safe, and intentional electric shock. Based on his analysis, Bernstein (1991) did not believe that the TASER was likely to be more dangerous than the electric fence.

[8] American National Standards Institute, "IEEE Guide for Safety in AC Substations. ANSI/IEEE Standard 80, 1986

Data taken by Stratbucker[9] on a modified AIR TASER® 34000 is shown in Figure 1. These data illustrate the relationship between the safety limit and a "typical" TASER device. Stratbucker reported peak current. For his data, we estimated the RMS current by taking the peak current in his report and assuming that the current pulse shape was identical to what we measured for the AIR TASER® 34000.

On the basis of animal studies, the amount of current needed to induce ventricular fibrillation with single unidirectional pulses is understood. The UL safety limit for ventricular fibrillation (Underwriters Laboratory, 1988) is shown in Figure 1 along with the output of variations of a modified AIR TASER® 34000. The International Electrotechnical Commission (IEC) Publication 479 (IEC, 1984) threshold for ventricular fibrillation is also shown. Data on physiological effects for rapid rise-time, short-duration, high-voltage, low-current impulses are available (Reilly, 1992)[10]. The UL limit shown in Figure 1 is based on data from single unidirectional pulses, but is used as the safety limit for both unidirectional and bi-directional pulses. Roy et al. (1985) reported up to an order of magnitude increase in threshold current for ventricular fibrillation when comparing unidirectional and bi-directional pulses.

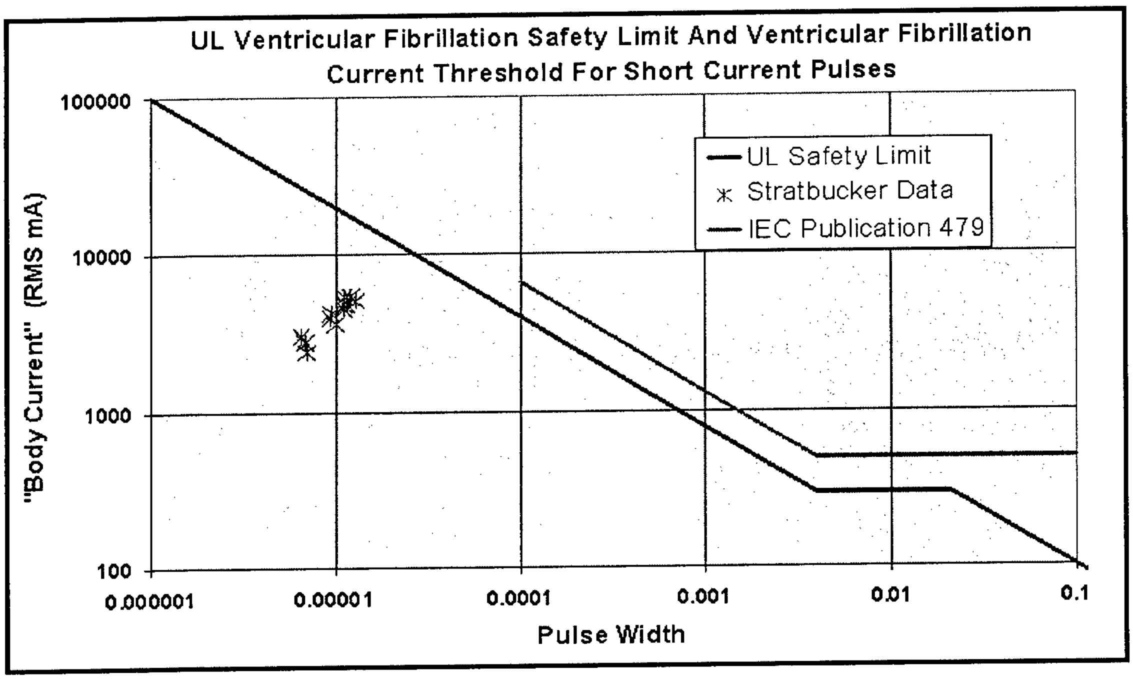


Figure 1. The UL Ventricular Fibrillation Limit for short current pulses and IEC Publication 479 ventricular fibrillation threshold.

[9] Stratbruker & Associates, Unpublished Paper on safety studies preformed in 1996 for Air TASER® on the Air TASER® 34000.

[10] Reilly 441-443.

Dr. R. A. Stratbucker (1996) (Omaha, NE), a consultant for TASER® International, performed a safety test of the Air TASER® Model 34000. Using the basic circuit of the TASER, he tested the effects of three power supplies, 9, 18 and 27 volts.[11] The output of the power supply was passed through a 0.22, 0.44, 0.66, or 0.88 microfarad capacitor and coupled to electrodes attached to an 18.2 kg Hampshire shoat (young pig) that was pre-medicated with atropine (0.02 mg/kg, IM) and sedated with ketamine (10 mg/kg) mixed with xylazine (2.01 mg/kg) and given IM. The animal was stimulated with output electrodes: 1) on the left hindquarter to determine the skeletal muscle response, and 2) vertically oriented on the anterior abdomen at the umbilicus to determine the mid-abdominal response. Electrodes were also placed in both the vertical and transverse orientation at the level of the cardiac apex to determine if stimulation caused a change in cardiac rhythm, which was detected by a battery-powered cardiograph. Each stimulus was 5 sec in duration. There was no indication of ectopic heartbeats or myocardial injury. Respiration was briefly arrested with some chest discharges, but returned spontaneously at cessation of stimulation. In all cases, both respiration and heart rate returned to normal within a few minutes. The pulse width into a 1000-ohm dummy load varied from 6.5 microsec at 9 volts and 0.22 microfarads to13 microsec at 27 volts and 0.88 microfarads.[12] Stratbucker did not define the methodology used for determining pulse width, which makes comparison to data from other sources difficult. The peak current at any voltage was lowest at 0.22 microfarads and highest at 0.88 microfarads.

Dr. Stratbucker's data (videotapes) were re-examined by the management of TASER® International (unpublished report), who noted that anesthetized animals showed minimal physical response when stimulated with the Model 34000 Air TASER®. This lack of response suggested that these stun systems were not greatly affecting the motor nerves and muscles and that the Model 34000 Air TASER® was primarily affecting the sensory nervous system causing pain-induced incapacitation. Highly-motivated, focused individuals, or those with certain central nervous system altering drugs in their system, have been shown capable of fighting through these effects. These findings suggest that the newer, higher power TASER® International Advanced TASER® M26, Model 44000 (Electro Muscular Disrupter [EMD]), with an 0.88 microfarad capacitor, functions by acting on the muscle efferent nerves causing involuntary muscle contractions. An alternative explanation is that the anesthetic is merely masking the effects of the lower power levels and/or that a threshold for involuntary neuromuscular disruption is exceeded by the more powerful M26.

Dr. Stratbucker and Dr. W. McDaniel (1993) of the Division of Cardiothoracic Surgery, University of Missouri, Columbia, MO, describe a series of tests to determine if external application of the TASER devices could cause ventricular fibrillation in canines. They report that 16 discharges of the Air TASER® and 192 discharges of the Advanced

---

[11] It should be noted here the voltage of the charging power supply should affect the output only a small amount, as the pulse voltage of the TASER is determined by a spark gap that discharges the capacitor into a pulse transformer.

[12] A dummy load is a resistor or series of resistors and test equipment that allows measurement of the electrical parameters of a device under controlled and repeatable conditions.

TASER® through electrodes in multiple configurations resulted in 0 episodes of ventricular fibrillation. In 3 animals they implanted a pair of separated 20-gauge spinal tap hypodermic needles through the chest wall to a depth of 2-3 cm so that the sharpened points just contacted the surface of the beating heart. They stimulated these electrodes with the Advanced TASER® and did not find any evidence of ventricular fibrillation with 13 stimulations. They gave their subjects sympathomimetic drugs (epinephrine and isoproterenol - doses or route not reported) and found that no combination of drugs or doses was associated with induction of ventricular fibrillation. They gave one animal toxic levels of ketamine (no dose or route reported), a close chemical relative of phencyclidine (PCP or angel dust), which has been implicated in a number of TASER-related deaths. They reported "no untoward cardiac effects" with repeated external applications of the output of the Advanced TASER®. Stratbucker and McDaniel (1993) did not report whether stimulation with TASER-like impulses, either external or internal, caused any type of alterations in cardiac activity.

RISKS OF TASER USE

Unfortunately, there is no way to track morbidity/mortality associated with the use of the TASER except by reports in refereed journals or reports in the media. A preliminary search of the Lexis-Nexus database indicates that there are several hundred articles dealing with TASERs in the popular literature (newspapers, magazines). Most of these reports deal with issues other than morbidity/mortality. There are only two studies in the refereed literature that deal with morbidity associated with TASER exposures.

Ordog et al. (1987) reported on the results of all people (n = 218) brought to the King/Drew Medical Center in Los Angeles who were shot with a TASER between July 1980 and December 1985. The mean age was 28 ± 4.8 (SD range 15-48, where 95% were male). The majority (86%) of the tasered people admitted to the hospital had a history of PCP abuse. The average number of darts was 2.3 (range 2.3 ± 0.93) and they were found in anterior chest (4%), posterior chest (39.0%), scrotum (0.5%), and upper limb (6.0%), gluteus maximus (12.0%), scalp (2.0%), anterior abdomen (12.5%), face (1.0%), and lower limb (23.0%). The average blood pressure of the affected individuals was 120/80 mm Hg (SD = 15/16) and the average pulse rate was 96 beats/min (SD = 21), suggesting no significant effect on these measures compared to a normal population. The patients spent an average of 6.5 h in the emergency room. The mortality rate was 1.4%. All of the patients who died (n = 3) were admitted in asystole. The darts were in the anterior thigh, buttocks, and back. Each of these three patients had high levels of PCP in their serum (0.156-0.43 μg/mL) and each went into cardiac arrest immediately upon being struck.

Kornblum and Reddy (1991) reported the results of the autopsy of 16 young males (20-40 years--5 Hispanics, 8 blacks, 3 Caucasians) whose deaths were associated with the TASER in Los Angeles County (TASER darts released by 10 Los Angeles police officers, 4 Los Angeles sheriffs, 1 Pomona police officer and 1 Beverly Hills police officer) between 1983 and 1987. Each person was engaged in some form of bizarre or unusual activity that caused his interaction with the police. Drugs, cocaine, PCP, or amphetamine were found in all but 3 cases. One to eight TASER wounds were found on each body. Kornblum and Reddy (1991) concluded that none of the deaths were caused by the TASER. Allen (1992) was the deputy medical examiner assigned to Case 6 of the Kornblum and Reddy (1991) series and he disagreed with their findings, believing that the TASER was a significant factor in the death of this individual. He claimed that pathologists in Los Angeles were under pressure from law enforcement officials to exclude the TASER as the cause of death.

Probably other deaths associated with TASER exposure have occurred outside of Los Angeles County during the 1980's. In the reports cited above, death in each case was attributed to drugs the person had ingested at the time the exposure occurred. It is unclear from reading these reports whether the person might have died because of effects from the drugs alone. If the TASER was a significant factor in the death of a physiologically-compromised individual, it would probably involve a transient physiological event that would not leave pathology such as a gunshot wound. Based on Stratbucker's and McDaniel's reports (1993, 1996) and our measurements taken for this report, it seems unlikely that this event was ventricular fibrillation. Given the likelihood of the absence of pathology, it is unknown how medical examiners in these cases (Ordog; Kornblum and Reddy; Allen) determined whether the exposure was a significant factor in these deaths or not. Regarding more recent reports in the popular media involving the TASER® International Advanced TASER® M26, Model 44000, it is again unknown how medical examiners determined that the TASER was not a significant factor in the deaths[13]. Based on the work of Stratbucker and McDaniel (1993) described above, a drug - TASER exposure interaction does not seem to be a significant factor in death, as none of their animals died as a result of being tasered after treatment with drugs. Following up on reports of morbidity and tracking new reports, should give some insight into the risk of morbidity as a result of exposure.

Most individuals have been tasered as a result of an interaction with law enforcement. Probably these incidents could not now be tracked. Law enforcement and corrections personnel who were tasered under quasi- controlled conditions as part of their training do not seem to have been followed to determine if there are any long-term effects or to obtain objective assessments of how effective the exposure was. Other than the data on people who were physiologically compromised, there is little, if any, injury data on other populations such as women, children, those with implanted devices such as pacemakers, and the elderly.

There is only one animal-based, safety-related experiment where the data were collected under controlled conditions. This particular study by Roy and Podgorski (1989) was

[13] Associated Press, April 3, 2002, "Hollywood man did not die from TASER® shot, report says"; Associated Press, March 8, 2002, "Philly M.E. (Medical Examiner) rules on man's death"; Gainesville Sun, February 15, 2002, "Jail Cleared in death of ex-EHS star

performed with a stun gun[14], whose output is qualitatively similar to the TASER. Roy and Podgorski (1989) applied a stun gun directly to the chest wall of an anesthetized swine and found that it induced asystole (absence of contractions of the heart). The pulse from the stun gun is high voltage (> 100 kV), short duration (<20 microsec), with current limited to less than 3.8 A.

EFFECTIVENESS

TASERs do not seem to be effective in all subjects. Kornblum and Reddy (1991) reported that the TASER was effective; that is, it provided some level of control of the subject's behavior about 80% of the time when used by the Los Angeles Police Department. There are other anecdotal reports, mostly found on the internet, suggesting that the effectiveness may be as low as 60%. Mr. Rick Smith, CEO of TASER® International (TASER International 2002 Tactical Conference, Las Vegas, Nevada, May 17-19, 2002) stated that individuals could be trained to continue goal-directed behavior during exposure from their TASER®International Air TASER® Model 34000. Both TASER manufacturers have introduced more powerful TASER devices (e.g., Tasertron Model 95HP and the TASER® International Advanced TASER® M26, Model 44000).

TASER-like devices have been demonstrated to be useful in subduing criminals by local law enforcement agencies for approximately 20 years. TASER® International collects voluntary reports of field exposures from police agencies. Examination, it is clear that the majority of the reports come from small to medium cities with very few, if any, coming from large metropolitan areas. Based on an analysis of sales records, TASER® International concluded that the database contains about 1/5 of the total number of exposures and it is unknown what bias is introduced in this non-random, voluntary sample. TASER® International also maintains a database of exposures that occur under quasi-controlled conditions, where police or corrections officials were exposed to the TASER. Anecdotal reports from the manufacturers or users are not considered valid databases since the subjects know they are going to be tasered and know what the TASER is expected to do. These anecdotal reports are essentially endorsements and should be viewed with the same critical eye as any endorsement. With the exception of these two databases, relatively little is known about the exposure conditions (i.e., number of exposures, location of darts/barbs on the body, duration of exposures) that led to the effective use of the device.

Prior to our study, there was only one animal-based effectiveness study in which the data were collected under controlled conditions Coate and Wargovich (1974) found that exposure to the output of a TF-1 TASER Electronic Gun did not disrupt performance of a

[14] The stun gun, which appeared commercially in 1983, requires the operator to physically apply the electrodes of the hand-held device to the subject's clothing or skin (see U. S. Patent 4486807 below). The output of the Nova XR-5000 (Nova Technologies, Austin, TX) stun gun has been shown to be similar to the TASER®.

learned task by monkeys. The monkeys were working on a continuous (Sidman) avoidance task. Inter-bar press interval and the avoidance of shock were used as metrics. The output of the TF-1 was 2-10 pulses/sec and 0.01 to 0.5 J/pulse. Unfortunately, this study is insufficient to fully assess effectiveness; additional research is required.

The literature does not contain objective criteria, other than a change in behavior, for determining if a TASER effect has occurred. The TASER effect seems to vary from subject to subject (e.g., apparently fully effective in <80% of humans), as described above. Therefore, the effectiveness of the TASER should be evaluated in unanesthetized animals that are approximately the same size as humans, working on goal-directed tasks.

METHODS

ELECTRICAL DEVICES

The Jaycor Sticky Shocker, the Tasertron Model TE86, the Tasertron Model 95HP, the TASER® International Air TASER® Model 34000, and the TASER® International Advanced TASER® Model 44000 M26 TASER®s were obtained from their respective manufacturers. The TASER manufacturers also supplied cartridges for each TASER and provided recommendations about the type of battery that should be used to power the TASER. The voltage and current output of the TASERs were quantified and the wave shape of the impulse was determined. A schematic of the test setup is shown in Figure 2.

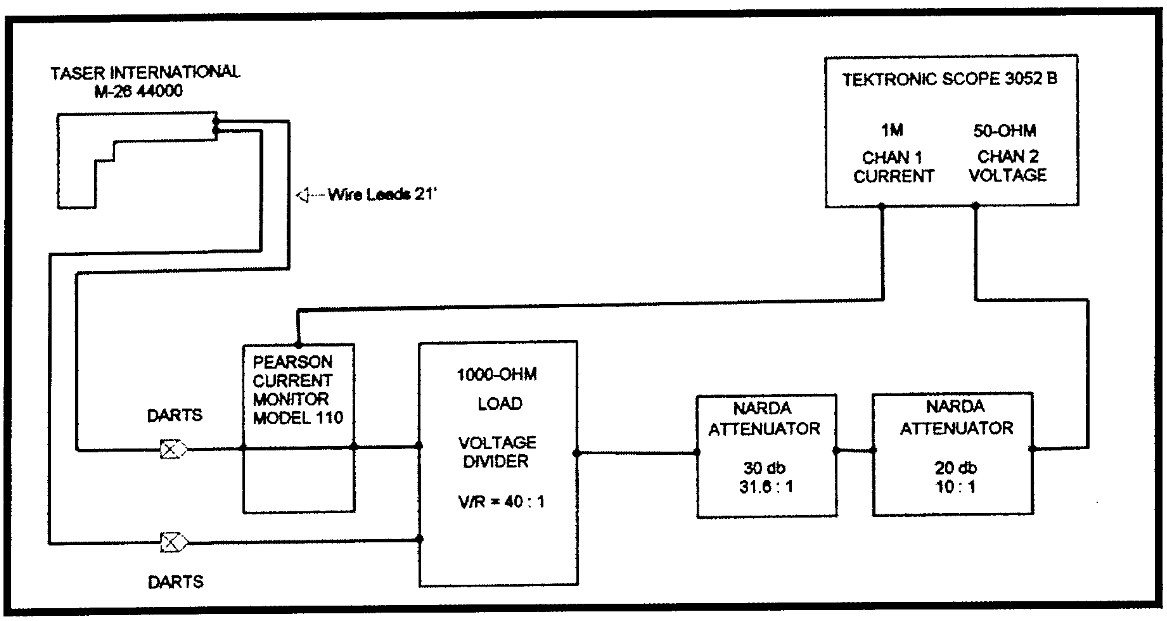


Figure 2. The dummy load (voltage divider) and test equipment.

The output voltage of each TASER was obtained using four different voltage divider dummy loads: 100, 1000, 5000, and 10,000 ohms. One thousand ohms is the nominal whole body impedance as described above. One hundred ohms approximates the impedance of the body when the skin is pierced. Five thousand and 10,000 ohms approximate the impedance that occurs when the darts imbedded in clothing and not touching the skin. The 100-ohm voltage divider consisted of a 100 and 0.27-ohm resistor. The 1000 and 10,000-ohm voltage dividers were composed of a string of ten 100- and 1000-ohm resistors, respectively. The 5000-ohm voltage divider consisted of ten 500-ohm resistors. All of the resistors were rated at 1 W. The readout resistor for the 1000, 5000, and 10,000-ohm voltage dividers was 50 ohms. The resistors were connected in series. Each voltage divider was housed in a coaxial environment. The chain of resistors served as the center conductor and was surrounded by 4 orthogonal stainless steel rods that were connected to the shield of the coax. The resistance of the two components of the voltage divider was determined before and after each TASER shot using a Model 189 Fluke True RMS Multi-meter Meter. (Everett, WA). The output of the voltage divider was used to drive a Model 769-20 and a 769-30 Narda High Powered Attenuator (Hauppauge, NY). The attenuators were rated at 20 and 30 dB, respectively, and were used to match the output impedance of the voltage divider and the input impedance of the oscilloscope. The peak output current of each TASER was determined with a Model 110 Pearson Current Monitor (Palo Alto, CA). The output of the voltage divider and the current monitor were displayed on a Model TDS 3052-B Tektronic Oscilloscope (Beaverton, OR).

BIO-BEHAVIORAL STUDIES

Swine were chosen because they approximate the same size of humans and their skin is very similar to that of humans. Further, the pyramidal cell in the motor strip of the cerebral cortex of the swine, its axon, the synapse(s) in the spinal cord, the alpha motor neuron, the neuromuscular synapse, and the muscles, including the individual muscle fibers, myofibrils, and sarcomeres are very similar to humans[15]. Swine behavior has been well described and swine are intelligent and capable of learning complex tasks (Hafez and Signoret, 1969).

Operant conditioning provides a simple method to take a response that occurs spontaneously and increase the likelihood of the response by reinforcing it. Individual swine were trained by the method of successive approximations or shaping to press a panel. Briefly, a swine that was food-deprived for 24-48 hours explored its environment and discovered food in the food well attached to the operant panel. Once the animal ate the food, the delivery of the food became contingent on its behavior. The first step was to reward the animal for facing the operant panel and remaining near it. Once this behavior was established, the animal was not reinforced until it approached the press panel. Then the animal was not reinforced until the animal touched the press panel. Steamed corn or horse feed served as the reinforcer and were delivered via a Whitmore Enterprises (San Antonio, TX) Model WE 1001 feed dispenser. Stimuli and reinforcers were delivered and responses were recorded by a Coulbourn Instrument (Allentown, PA) Universal Environmental Interface (E91-12), an Environmental Interface Control (S91-12), a Retriggerable One Shot (S52-12), and a Predetermining Counter (S43-30). The rate of bar pressing was recorded via a CWE AC/DC BioAmplifier, Model BMA-931 and panel-pressing signals were displayed and stored by WINDAQ software (DATAQ Instruments, Inc). The swine's rate of response was very stable (that is, the animal pressed the press panel rapidly and consumed its food reward). Then the swine was moved to a Fixed Ratio

[15] "Comparative Anatomy and Physiology of the Pig" by M. Michael Swindle, D.V.M. and Allison C. Smith, D.V.M. published on the Internet (http://www.nal.usda.gov/awic/pubs/swine/swine.htm) by the United States Department of Agriculture, Agricultural Research Service, National Agricultural Library, Animal Welfare Information Center, 10301 Baltimore Avenue, Beltsville, MD 20705-2351 and edited by Cynthia P. Smith, M.S.

Schedule of 3 (that is, the animal pressed the press panel three times before it was reinforced). The order in which each swine was exposed to the individual TASER was determined randomly to minimize ordering effects.

Each swine was initially exposed to the output of a randomly-selected TASER for 15 sec. There was a minimum rest period of 45 hours between succeeding exposures. The initial exposures were accomplished while the swine were bar pressing. After the second exposure, independent of the devices they were exposed to, the swine refused to approach the bar and food well. Therefore, the test chamber was reconfigured and the bar press apparatus and food well were replaced with a bowl that contained food. After the third exposure, the swine refused to approach the food bowl and vigorously resisted entering the test chamber. On all subsequent trials, the animals had to be placed into the chamber.

RESULTS

ELECTRICAL DEVICES

The electrical and bio-behavioral results are summarized in Table 1 and described in detail below.

TABLE 1. Electrical Parameters and bio-behavioral effects of TASERs.

Device	Decreasing Muscle Coordination				TASER Electrical Characteristics		
	Circle	Jump Against Wall	Jump Over Wall	Lost Posture	Peak Current (Amps)	RMS Current (Amps)	5% Of Peak Pulse Width (nsec)
Jaycor Sticky Shocker	10	4	0	0	11	2.7	29,000
Tasertron TE 86	7	4	1	0	6	3.5	8,700
Tasertron HP 95	11	3	1	0	8.5	4.8	13,000
TASER Int Model 34000	6	7	0	0	9	3.5	20,000
TASER Int Model 44000	10	10	0	7	14	5.5	20,000

The pulse characteristics and current envelope of the Jaycor Sticky Shocker, Tasertron Model TE86 TASER®[16], the Tasertron 95HP TASER®, the TASER® International Air TASER® 34000 and TASER® International Advanced TASER® M26, Model 44000 discharging into a 1000-ohm dummy load are shown in Figure 3.

The curves represent averaged responses. The high frequency components at the beginning of the main impulses are switch noise generated by an air gap switch. The high frequency components have very little impact on the effectiveness of the device because the total charge transferred during that time is low when compared to that of the rest of the pulse. The output of the Sticky Shocker, the two Tasertron TASER®s, and the TASER® International Air TASER® have a positive peak current of less than 10 Amps and a pulse width at half maximum of less than 5000 nsec. The TASER® International M26 TASER® has a positive peak current of 14 Amps and a pulse width at half maximum of approximately 10,000 nsec.

[16] This version of the TASER® is as close to the "original" TASER® as currently commercially available.

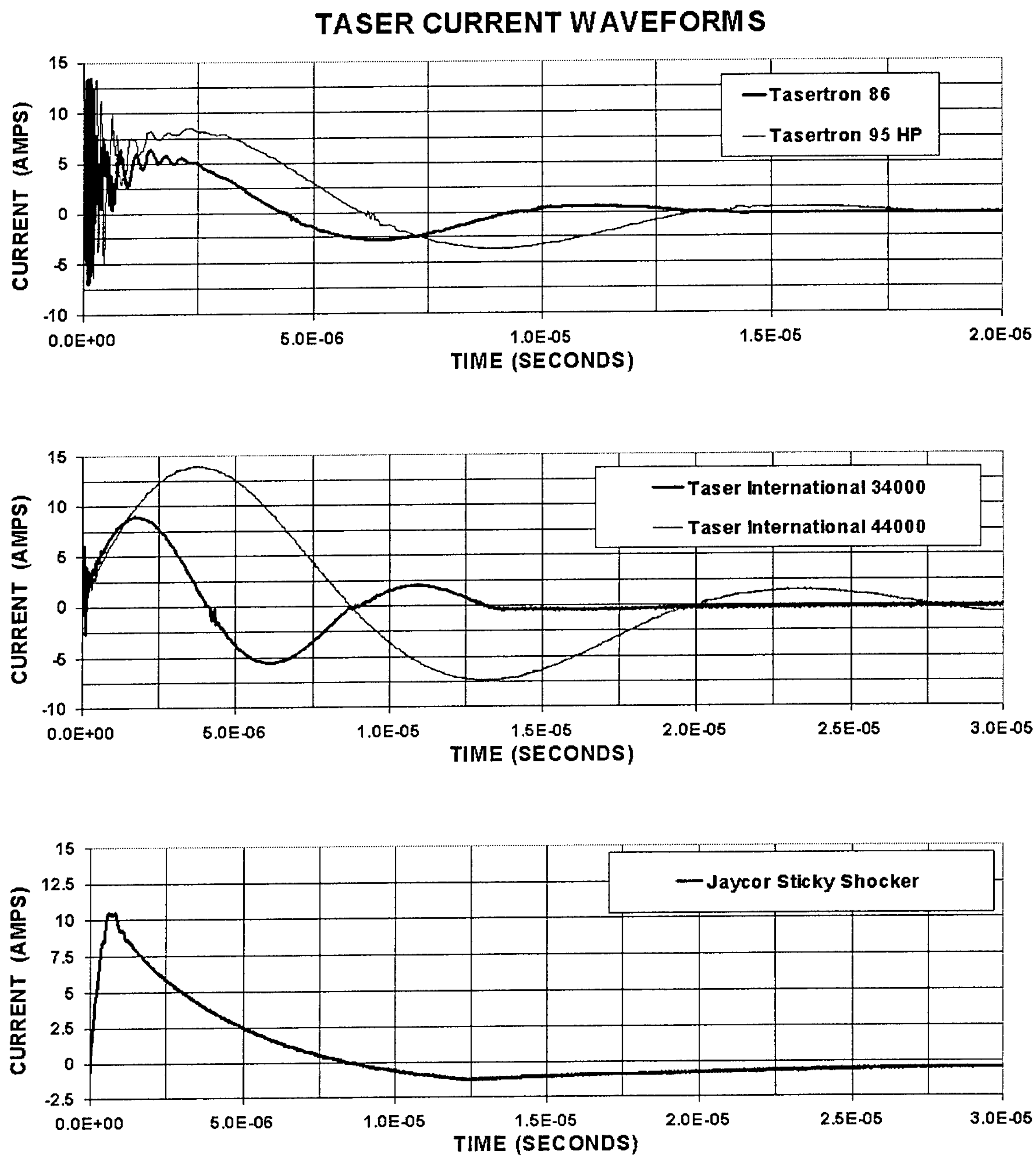


Figure 3. The TASER current waveforms when discharged into 1000 Ohm loads. With the exception of the Jaycor Sticky Shocker, all of the waveforms are that of an exponentially damped sinusoid. The Sticky Shocker is an exponentially damped monopolar pulse.

Figure 4 shows the relationship of TASER data we acquired to the UL Pulsed Safety Limit. For comparison purposes, data is included from Stratbucker for two of his setups that were most similar to the Air TASER® 34000 and Air TASER® 44000. For the Stratbucker data, we estimated the RMS current by taking the peak current in his report and assuming that the current pulse shape was identical to what we measured for the Air

TASER® 34000. Note RMS current is similar, but the pulse width is not. A pulse from these TASERs (with the exception of the Jaycor Sticky Shocker) is sinusoidal with a rapid exponential decay. To determine both pulse width and integration limits for the RMS current, we used 5% of peak current as described by Reilly (1992). The Stratbucker report did not mention a method of pulse width determination.

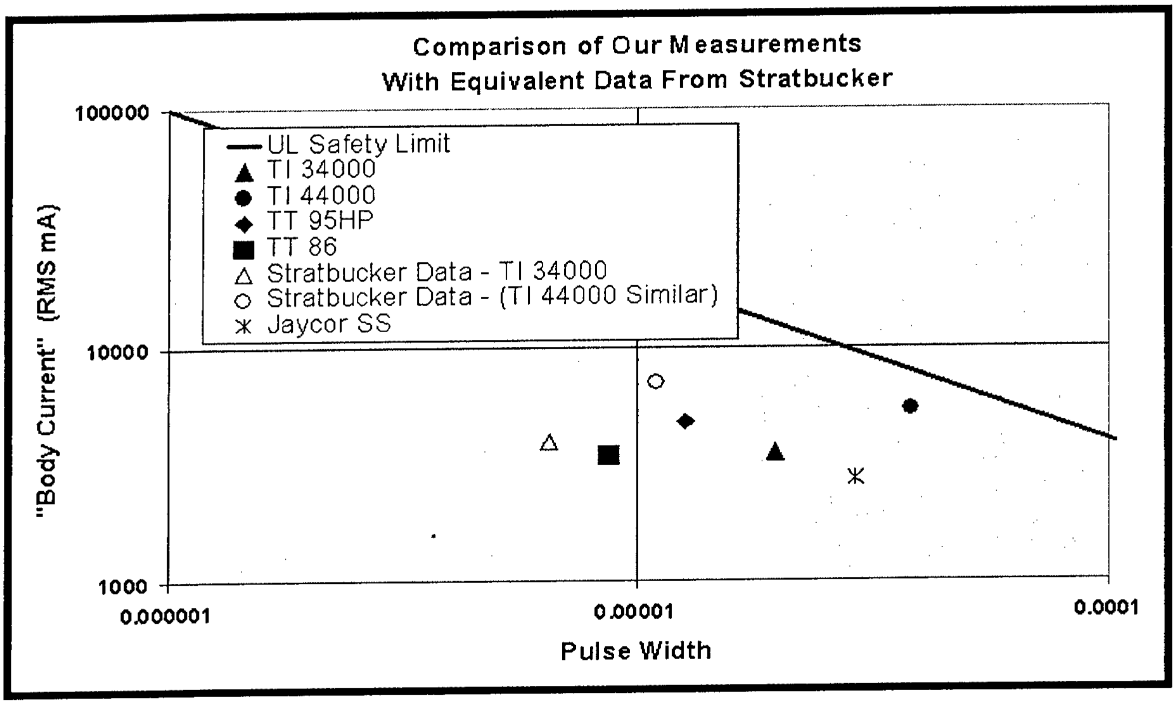


Figure 4. Data comparison with that taken by Stratbucker on a modified AIR TASER® 34000.

TABLE 2. Charge Flux of TASERs.

Device	Total Charge Flux (Coulombs)	Net Charge Flux (Coulombs)
Jaycor Sticky Shocker	6.3×10^{-5}	1.8×10^{-5}
Tasertron TE 86	2.9×10^{-5}	8.2×10^{-6}
Tasertron HP 95	5.4×10^{-5}	1.6×10^{-5}
TASER Int Model 34000	5.1×10^{-5}	7.5×10^{-6}
TASER Int Model 44000	1.5×10^{-4}	1.3×10^{-5}

Table 2 shows two additional electrical parameters that we have calculated for each TASER. They are the total charge flux and the net charge flux through the dummy load. The total charge flux is the total charge (in coulombs) passing through the load in *both* directions. The net charge flux is the total charge in one direction subtracted from the charge in the other direction.

BIO-BEHAVIORAL STUDIES

The two points of placement of the TASER darts for the Jaycor Sticky Shocker, Tasertron Model TE86 TASER®[17], the Tasertron 95HP TASER®, the TASER® International Air TASER® 34000, and TASER® International Advanced TASER® M26 Model 44000 are shown in Figures 5-9, respectively[18]. Since a launcher was not provided, the Jaycor Sticky Shocker was attached to the swine with a harness applied just behind the forelimbs. The electrodes of the Sticky Shocker did not make good contact with the surface of the swine; therefore, wires with alligator clips were soldered to these electrodes and previously-used (sterilized) TASER darts were utilized to apply the current to the swine. The Tasertron Model TE86 TASER® and TASER® International Air TASER® Model 34000 were retrofitted with laser sights to facilitate aiming.

---

[17] This version of the TASER® is as close to the "original" TASER® as currently commercially available.
[18] The numbers in parenthesis following the behavioral descriptions refer to the dart placement as shown in Figures 4-8

JAYCOR STICKY SHOCKER

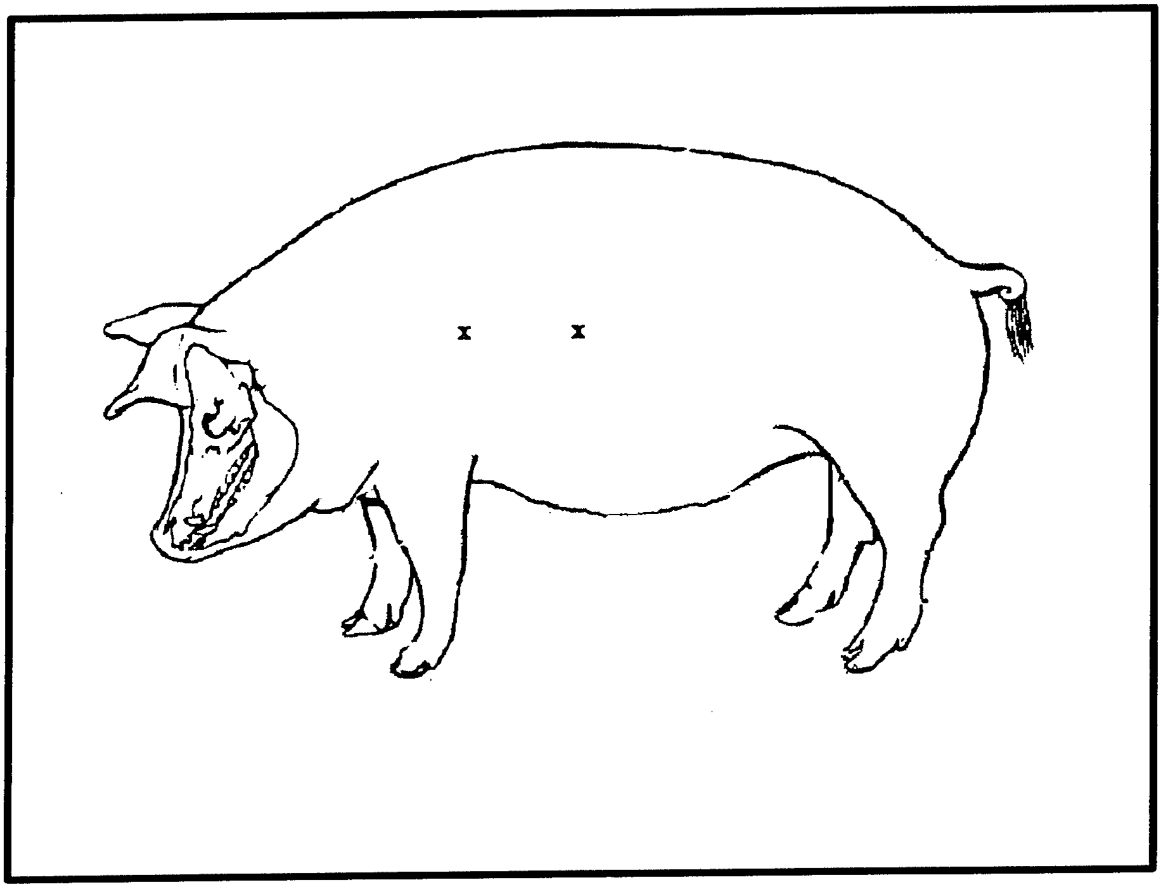


Figure 5. Placement of the electrodes for the Jaycor Sticky Shocker.

In eleven swine, the output of the Sticky Shocker induced rhythmic contractions of the muscles of the thorax and abdomen, mostly limited to the side of the swine where the electrodes were placed and had minimal to no effect on the leg muscles. None of the swine lost posture. While being tasered, all of the swine ran in a circle, two of the swine running backward and the remaining swine running forward. Four of the swine jumped up against the wall of the test chamber, while the rear legs remained on the ground. Immediately after the current was turned off, the behavior of the swine appeared to return to normal.

TASERTRON MODEL TE86 TASER®

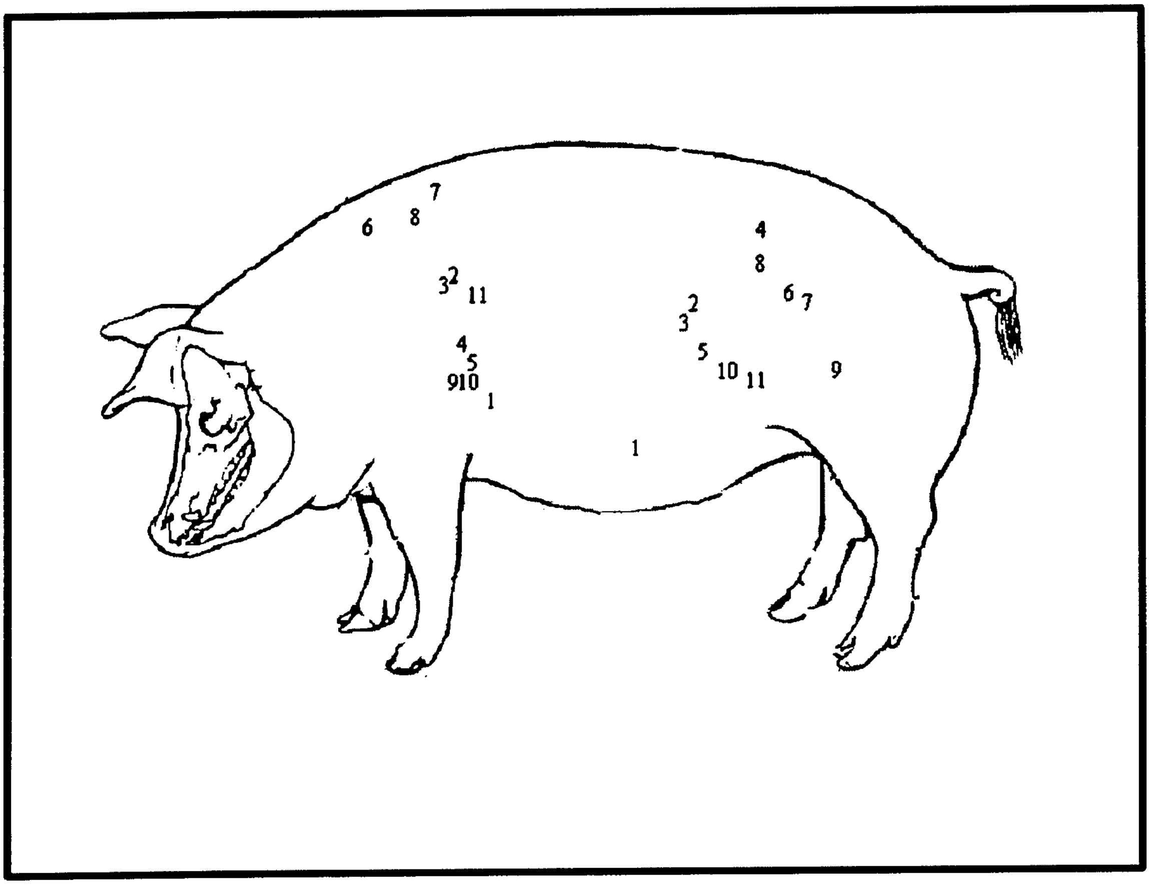


Figure 6. Dart placement for the TASERTRON MODEL TE86 TASER®.

The output of the Tasertron TE86 caused rhythmic contractions of the muscles of the thorax and abdomen on the side of the swine where the electrodes were placed, although in two swine, the contractions were bilateral (5, 7). In four of the swine, the rear legs also showed contractions (2, 3, 9, 11); in one swine, the front leg was affected (1); and in two swine, both front and rear legs were affected (7, 10). None of the swine lost posture. One of the swine jumped upward against a wall three times while being tasered and one of its front hooves reached approximately 6 feet off the ground on one of the jumps (5). One of the swine jumped over a 3-foot fence (4), and one jumped against a wall with one of its rear hooves approximately 3 feet off the ground (10). Eight of the swine ran in a circle, while three paced back and forth along one wall.

TASTERTRON Model 95HP

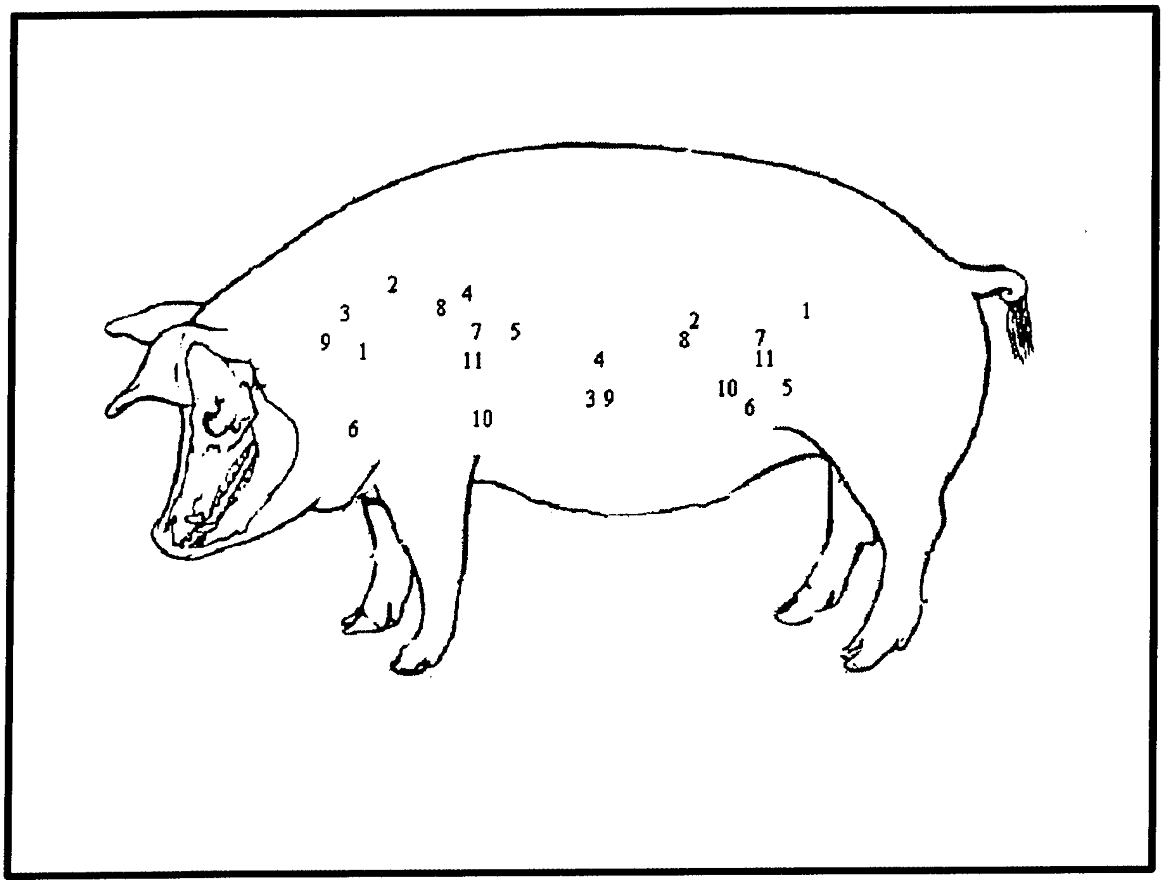


Figure 7. Dart placement for TASTERTRON Model 95HP.

The Tasertron Model 95HP caused localized muscle contraction in one swine (1), contractions of the muscles of the thorax and abdomen in three swine (2, 8, 11), the muscles of the thorax and abdomen plus the rear leg in three swine (4, 6, 7), and three swine showed bi-lateral contractions of the rear legs (5, 9, 10). One of these swine made a hopping motion on the rear legs (9). One of the swine jumped back and forth over a 2.5-foot fence (3) and three of the swine jumped at the wall of the exposure chamber, while the rear legs remained on the floor (1, 7, 11).

TASER® INTERNATIONAL AIR TASER® MODEL 34000

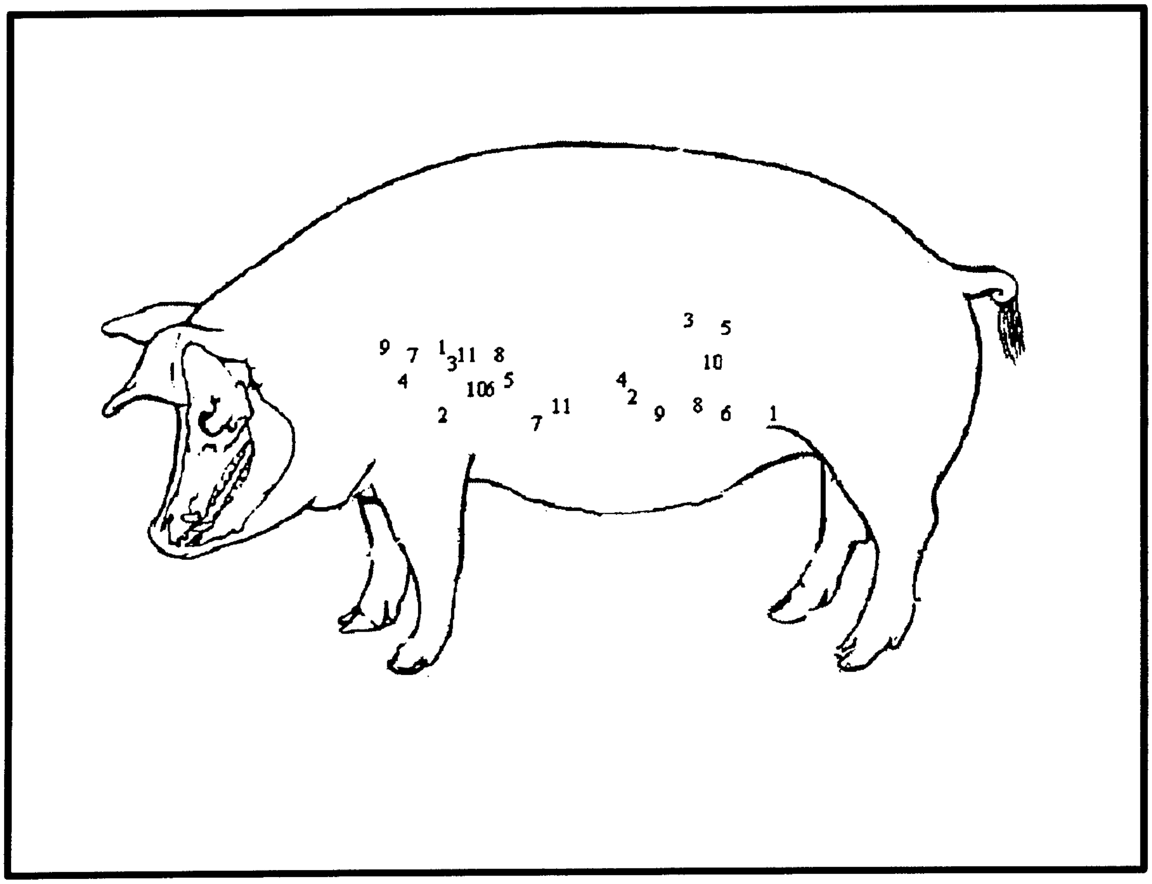


Figure 8. Dart placement for the TASER® INTERNATIONAL AIR TASER® MODEL 34000.

The TASER® International Air TASER® Model 34000 caused bilateral contractions of the abdomen and thorax in 6 swine (1, 2, 3, 4, 5, 11), and bilateral contractions that involved the rear legs in two swine (6 and 7), while the remaining swine showed unilateral contractions of the abdomen and thorax on the side where the darts were located (8, 9, 10). One of the swine lost posture momentarily, but righted itself immediately. It was not clear if the loss of posture was due to the TASER effect or because it slipped on the floor. All of the swine engaged in circling behavior. Seven of the swine jumped at the wall. The rear feet of four of these swine remained on the ground (1, 6, 7, 11). The rear legs of two of the swine came 1 to 2 feet off the ground (3, 4) and one of the swine made 4 jumps in which the rear feet came 1-2 feet off the ground (9).

TASER® INTERNATIONAL ADVANCED TASER® M26, MODEL 44000

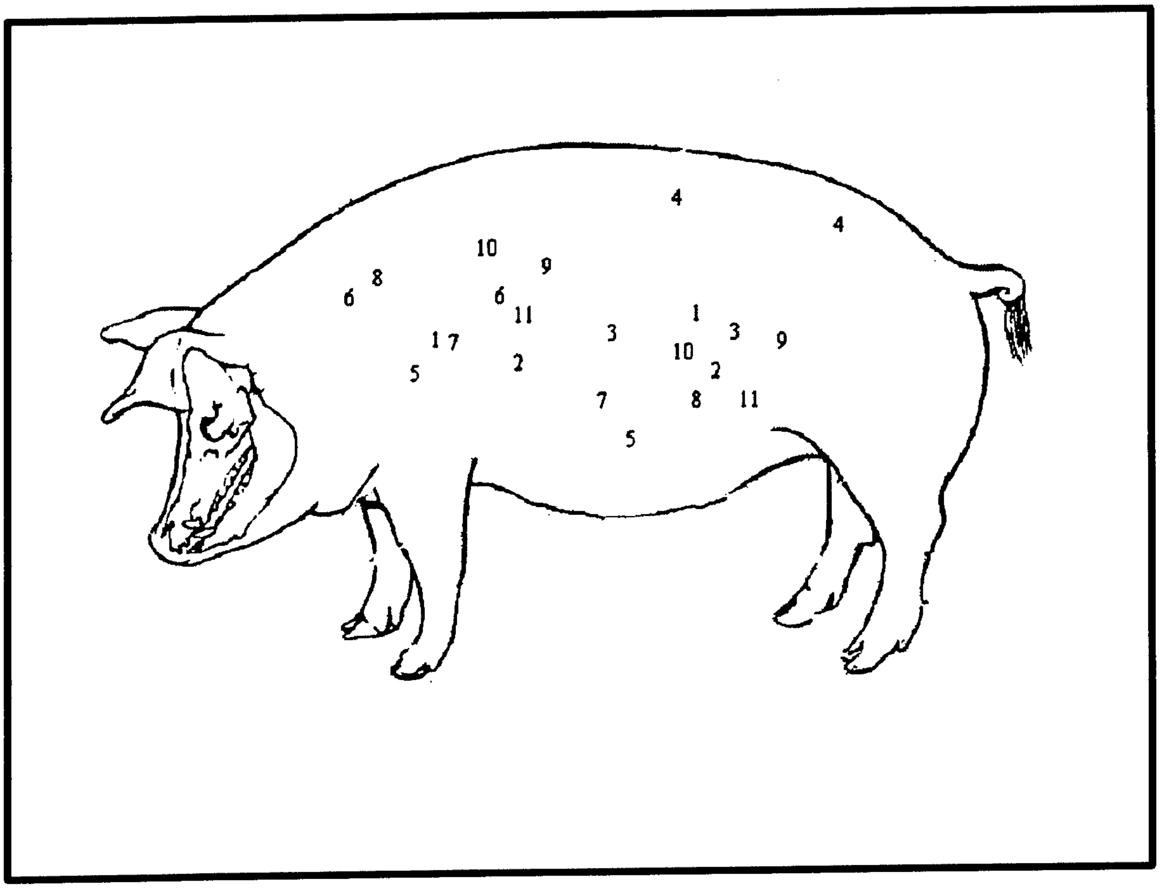


Figure 9. Dart placements for TASER® INTERNATIONAL ADVANCED TASER® M26, MODEL 44000.

All of the swine exposed to the output of the TASER® International TASER® Model 44000, M26 displayed circling, where 3 ran in small tight circles (3, 5, 6). All of the swine showed bilateral contractions of the thorax and abdomen, where 2 of the swine appeared to lose control of the rear legs (4, 9) and 3 appeared to lose control of the front legs (5, 6, 10), or all of the legs (1, 2, 3, 8). While being tasered, two of the swine were able to jump - one jumped against the wall twice (3) and the second (2) jumped upward with all 4 hooves off the ground approximately 2 feet. All but three of the swine (3, 7, 11) lost posture (i.e., lying on side with all four limbs off the ground). Swine 2 lost posture within 1 sec, was down for 2 sec, regained posture but immediately lost posture for 2 sec. The swine was able to jump with both front feet off the floor and against the wall 2.12 sec after regaining posture. Swine 4 lost posture at 3 sec, swine 5 at 8 sec, swine 6 at 7 sec, swine 8 at 10 sec and these swine did not regain posture until the end of the exposure. Swine 10 lost posture at 15 sec and was down for 2 sec, when it regained posture. Swine 9 lost posture at 2 sec and regained it at 5 sec and lost posture again at 15 sec for 3 sec.

CONCLUSIONS

The effects of the Jaycor Sticky Shocker, the Tasertron Model TE86, the Tasertron Model 95HP, and the TASER® International Air TASER® Model 34000 were similar. None of the swine exposed to them lost posture. Most of the swine ran in circles. While being tasered, some of the swine jumped, either against the wall or over a wall. For example, one of the swine being tasered with the Tasertron Model TE86 was able to jump against the wall and its front hoof reached 6 ft off the ground. A swine being tasered with Tasertron Model 95HP was able to jump back and forth over a 2.5-ft wall. In another example, a swine being tasered with the TASER® International Air TASER® Model 34000 was able to jump against the wall 4 times, where it's rear hooves were 1-2 ft off the ground. These TASERs allowed the swine to retain control of their muscles and act in a relatively coordinated but erratic manner (maintain posture, circle, and jump). Based on our results, it is possible a human subject exposed to these TASERs would be able to move in a coordinated manner towards a goal or to run away and escape. This would be in agreement with the claim individuals could be trained to continue goal-directed behavior during exposure from the TASER® International Air TASER® Model 34000. It is not clear if a human subject exposed to one of these TASERs would retain enough control over their muscles to engage in more complex and coordinated learned behaviors, such as aiming and firing a weapon.

Some of the effects of the TASER® International Advanced TASER® Model 44000, M26 Electro-Muscular Disrupter were similar to the other TASERs, where the swine vocalized loudly and ran in circles. They also demonstrated bilateral contractions of the muscles of the abdomen, thorax, and legs. However, in contrast to the other TASERs, seven of the 11 swine exposed to the output of this TASER lost posture. Two of the 7 were able to regain posture while being tasered. A human subject tasered with this TASER should have great difficulty retaining enough control over his muscles to engage in a complex and coordinated learned behavior, such as aiming and firing a weapon, or move in a coordinated manner toward or away from a goal.

The relative effectiveness of the various TASERs appear to be related to the total charge flux output from the TASERs. The total charge flux of the TASER® International Advanced TASER® Model 44000 was by far the highest, with the Jaycor Sticky Shocker, the Tasertron Model 95HP, and the TASER® International Air TASER® Model 34000 grouped together at a value of about 3 times less than the TASER® International Advanced TASER® Model 44000, and the Tasertron Model TE86 being about 5 times less than the TASER® International Advanced TASER® Model 44000. These numbers correlate well with the observed loss of posture by only the TASER® International Advanced TASER® Model 44000. Maximizing the total charge flux output from a TASER should be the basis for any program intending to increase the TASER effectiveness.

RECOMMENDATIONS

1) Using information gathered, with the TASER® International Advanced TASER® Model 44000, M26 as the starting point, determine if the TASER effect can be optimized by manipulation of pulse amplitude, pulse duration, inter-pulse interval, and darts location and separation.
   a. Determine if the TASER pulse delivered via TASER darts implanted in the surface of the chest can cause cardiac arrhythmias or ventricular fibrillation.
   b. Determine if morbidity or mortality can be demonstrated under controlled conditions. Identify any pathology associated with TASER exposure.
   c. Determine the role of drugs (cocaine, ketamine) or stress hormones on the TASER effect and their influence on the risk of morbidity/mortality.

2) Determine if the exposure conditions which are determined to be optimal for effectiveness pose a risk to the health and safety of the target up to and including death.

3) Perform a prospective study of human field exposures to determine the effectiveness and risks associated with the use of the TASER. This study could be done in parallel with the animal studies described above and could be done in collaboration with the National Institute of Justice and selected law enforcement departments.

ACKNOWLEDGEMENTS

This work was supported by National Institute of Justice (NIJ) Inter-Agency Agreement No. OJP-2000-RD-R-079. Joseph Cecconi, Deputy Director, Senior Program Manager, was the project manager for NIJ. The authors wish to thank Tasertron, TASER® International, and Jaycor for supplying the devices used in this study.

REFERENCES

Allen, T. B. Discussion of "Effects of the TASER® in fatalities involving police confrontation" [letter; comment]. *J. Forensic. Sci.* 1992 Jul; 37(4): 956-8

Alon, G. Principles of electrical stimulation. In: Nelson, R. M. and Currier, D. P. (eds). Clinical Electrotherapy, Appleton & Lance, Norwalk, CT. 1991

Bernstein, T. Electrical shock hazards and safety standards. *IEEE Trans. Educ.* 1991 34(3): 216-222

Coate, W. B. and Wargovich, M. J. Evaluation of TASER® (TF-1 TASER® Electronic Gun) effect on train monkeys. Final report. Aberdeen Proving Ground, Maryland: U.S. Army Human Engineering Laboratory, June, 1974

Dawalibi, F. P., Southey, R. D., and Baishiki, R. S. Validity of conventional approaches for calculating body currents. IEEE Trans. Power Delivery 1990, 5, 613-26

Hafez, E. S. E. and Signoret, J. P. The behavior of swine. In: Hafez, E. S. E. (ed.) The behavior of domestic animals, Williams & Wilkins, Baltimore, 1969

International Electrotechnical Commission. Effects of current passing through the human body, Part 1: General aspects (Publication 479-1), International Electrotechnical Commission, Geneva, Switzerland. 1984

Kornblum, R. N. and Reddy, S. K. Effects of the TASER® in fatalities involving police confrontation [see comments]. *J. Forensic. Sci.* 1991 Mar; 36(2): 434-8

Liang, M. T. and Norris, S. Effects of skin blood flow and temperature on bioelectric impedance after exercise. *Med. Sci. Sports. Exerc.* 1993 Nov; 25(11): 1231-9

O'Brien, D. J. Electronic weaponry--a question of safety [published erratum appears in Ann Emerg Med 1991 Sep; 20(9):1031]. *Ann. Emerg. Med.* 1991 May; 20(5): 583-7

Ordog, G. J., Wasserberger, J., Schlater, T., and Balasubramanium, S. Electronic gun (Taser) injuries. *Ann. Emerg. Med.* 1987 Jan; 16(1): 73-8

Reilly, J. P. Electrical Stimulation and Electropathology. Cambridge University Press, NY, 1992

Robinson, M. N., Brooks, C. G., and Renshaw, G. D. Electric shock devices and their effects on the human body. *Med. Sci. Law.* 1990 Oct; 30(4): 285-300

Roy, O. Z. and Podgorski, A. S. Tests on a shocking device--the stun gun. *Med. Biol. Eng. Comput.* 1989 Jul; 27(4): 445-8

Roy, O. Z., Mortimer, A. J., Trollope, B. J., and Villeneuve, E. J. Electrical stimulation of the isolated rabbit heart by short duration transients. In: Bridges, J. E., Ford, G. L., Sherman, I. A., Vainberg, M. (eds). Electrical Shock Safety Criteria, Pergamon Press, NY, 1985

Smith, D. C. Effects of skin blood flow and temperature on skin--electrode impedance and offset potential: measurements at low alternating current density. *J. Med. Eng. Technol.* 1992 May-Jun; 16(3): 112-6

Stratbucker, R.A. White paper written for AIR TASER® Incorporated, 1996

Stratbucker, R.A. and McDaniel, W.C. White paper written for AIR TASER® Incorporated, 1993

Taylor, R. J. Body impedance for transient high voltage currents. In J.E. Bridges, G. L. Ford, I. A. Sherman, and V. Vainberg (eds) *Electric Shock Safety Criteria*, Pergamon Press, 1995, pp251-58

Urbscheit, N. L. Review of physiology in Nelson, R. M. and Currier, D. P. (eds) Clinical Electrotherapy, Appleton & Lance, Norwalk, CT, 1991

Yamamoto, Y. Measurement and analysis of skin electrical impedance. *Acta Derm. Venereol. Suppl. Stockh.* 1994; 185: 34-8

Zarowitz, B. J. and Pilla, A. M. Bioelectrical impedance in clinical practice. *DICP.* 1989 Jul-Aug; 23(7-8): 548-55

Zylich, N. TASER® evaluation and analysis. *United States Consumer Product Safety Commission Memorandum*, reference No. 530959; 76, N. P. Zylich: Feb 14, 1976