Physiological Model of Excited Delirium

Final Report 2010

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Contents

Background

Although the effects of conductive energy weapons (CEWs) on healthy, anesthetized swine and normal human beings appear to be transient (Jauchem 2010), there have been concerns raised about their use in vulnerable populations (Lakkireddy, Wallick et al. 2006). These populations include those individuals who have a compromised physiology due to a variety of reasons including drug abuse and psychosis. One of the most common terms used to describe individuals in this abnormal state is excited delirium (ED). Excited delirium has been defined as the onset of a temporary disruption in awareness and cognition along with aggressive or violent actions (Di Maio 2006). Some signs associated with excited delirium include tachycardia (rapid heart rate), hyperthermia (elevated temperature), hypotension (low blood pressure), dehydration, and catecholamine (norepinephrine and epinephrine) release causing added stress on the heart. There is much debate about the existence of this syndrome and its role in fatalities proximal to CEW use. A recent report from Nova Scotia (2009) provided an overview of the issues surrounding the use of the ED as a descriptor for the signs and symptoms widely recognized in the field. It was suggested that the term autonomic hyperarousal state (AHS) be used in place of ED. This term is more appropriate since it accurately describes the majority of signs and symptoms seen in the field.

The type of physiological effects resulting from the combination of AHS and the use of CEWs are not yet well known. Several studies have tested a CEW on swine in various abnormal states (Lakkireddy, Wallick et al. 2006; Nanthakumar, Billingsley et al. 2006). All of these studies focused on various aspects of the AHS signs and symptoms. Lakkireddy et al. (2006) and Nathakumar et al. (2006) both used an animal model and a pharmacological agent. Lakkireddy et al. examined the effects of a single high-dose (8mg/kg) of cocaine given over a 30-minute period prior to CEW exposure in a sus scrofa domestica model (Lakkireddy, Wallick et al. 2006). They found that exposure to cocaine and CEW did not cause ventricular fibrillation (VF) but actually increased the tolerance to VF (Lakkireddy, Wallick et al. 2006). It is recognized that a single dose of cocaine can increase heart rate; it may not capture the effects seen in the field on repeated cocaine users. Nanthakumar et al. investigated the cardiac effect of a pharmacologic stress (infusion of epinephrine) with CEW exposure in the same animal model (Nanthakumar, Billingsley et al. 2006). The authors found that this simulated stress corresponded with episodes of tachycardia and ventricular fibrillation (Nanthakumar, Billingsley et al. 2006).

Strenuous physical activity has been shown to cause an increase in norepinephrine and epinephrine and stimulation of alpha and beta receptors (Di Maio 2006). Relying on this physiological response of the body, Vilke et al. (2009) and Ho et al. (2009), both used exercise to induce a physiological stress in humans. Vilke et al. (2009) recruited 30 police volunteers to undergo a “vigorous exercise” protocol prior to exposure with the X26. Cardio-respiratory and blood gas analysis was performed before, during and after a standard 5 second TASER – X26 exposure. With each subject serving as his/her own control, significant changes were noted during the TASER portion of the study in regards to systolic blood pressure at baseline and heart rate at 5, 30 and 60 minutes post-exposure.

Ho et al. (2009 a,b) used a similar protocol where they recruited 38 subjects to complete an exercise/CEW protocol. Each subject was instructed to perform a series of push-ups for 30 seconds followed by running on a treadmill at 8 mph at an 8 percent incline until the subject

could “no longer keep up with the pace of the treadmill.” After this exercise regimen, each subject was given a 15 second exposure with a TASER –X26. Blood was drawn immediately after exercise, immediately after exposure and 16 to 24 hours after exposure (Ho, Dawes et al. 2009). They concluded that there was not a worsening of pH or Troponin associated with the exposures. Decreases in pCO2 and K+ were reported with an increase in lactate post-exposure, but all levels returned to baseline values with the exception of lactate which was below baseline (Ho, Dawes et al. 2009). In a parallel study, ECG recording were examined and it was concluded that no detectable arrhythmias were presented given the CEW exposure and physically exhausted human (Ho, Dawes et al. 2009).

Although these studies have provided great insights into CEW use in physiologically stressed states, there are limitations including the transient effects of exercise that may or may not be present in the real world scenario. One method for inducing stress in the porcine physiology model is using a controlled hemorrhage [8]. This model has been used as a shock model since it allows the animal to be placed in a surgical plane of anesthesia and it can evoke tachycardia, hypotension and catecholomine release as a compensatory mechanism. All of these responses have been reported with AHS along with hyperthermia. There are two basic types of hemorrhage models: fixed pressure (Wiggers Model) and fixed volume. The fixed pressure model involves removing blood from the specimen until a predetermined mean arterial pressure is achieved (Swindle, Smith et al. 1988). Once this pressure is achieved, it is maintained by either removing more blood or re-infusing shed blood. The fixed volume method involves removing a set volume of blood usually based on the mass of the specimen. The blood is usually not re-infused, however it can be if needed. Although both of these models were originally designed to replicate hemorrhagic shock, the resulting patho-physiology created is representative of that seen in AHS. In order to determine whether severe physiologic stress in combination with the use of a CEW would cause a lethal or serious adverse physiological effect, the current study uses a modified fixed-volume hemorrhage model along with externally warming to create the reported patho-physiology.

The goal of the current study was to use the previously developed methodology to establish the safety of CEW exposures on individuals experiencing a physiological stressful state using an exposure protocol of a more probably scenario. For this study, an anaesthetized swine model subjected to a physiological stress of a controlled hemorrhage and hyperthermia was used. The physiological outcomes of this group were compared with a group subjected to a group that underwent the physiological stress only. Two different exposure patterns were evaluated: three exposures (5 on, 5 off) and a single exposure.

Methods

Subjects

Approval was garnered from the Wayne State University Animal Investigation Committee (AIC) prior to commencement of the study. Five Yorkshire-cross male swine with an average weight of 46.8 kg +/- 0.8 kg (103.2 lbs, +/- 1.8 lbs), were tested to assess the effects of a physiological stress and 3 exposures to a CEW (experimental group). This group was compared with a (control) group receiving the stress only previously tested and analyzed of three male swine with an average weight of 47.2 kg +/- 4.5 kg (104.1 lbs +/- 9.9 lbs). Five Yorkshire-cross male swine

with an average weight of 42.2 kg +/- 2.6 kg (92.9 lbs, +/- 5.8 lbs), were tested to assess the effects of a physiological stress and 1 exposure to a CEW (experimental group). This group was compared with a (control) group receiving the stress only of five five Yorkshire-cross male swine (one from the first control group) with an average weight of 44.3 kg +/- 4.4 kg (97.4 lbs, +/- 9.7 lbs).

Surgical Procedures and Instrumentation

All animals were sedated with an intramuscular injection of 33 mg/kg ketamine in combination with 0.5 mg/kg midazolam. A catheter was inserted into the ear vein and maintenance anesthesia was administered with a continuous intravenous pump using a combination of 6-10 mg/kg/hr ketamine, 2 mg/kg/hr midazolam and 30 µg/kg/hr fentanyl. After a plane of surgical anesthesia was achieved, the right carotid artery and right external jugular vein were surgically exposed. The right carotid artery was cannulated for systemic arterial blood pressure measurement and to obtain blood samples. A #7 French Swan Ganz® thermodilution catheter was inserted into the right external jugular vein to measure cardiac output, central venous pressure, and pulmonary arterial pressure. A cardiac output computer was used to determine cardiac output by thermodilution. ECG electrodes were secured on the distal aspect of all 4 extremities and the leads and transducers were connected to the appropriate signal conditioners. Data were recorded digitally and stored for subsequent analysis at a sample rate of 200-300 hertz.

Physiological Stress

The experimental groups and the control stress groups were subjected to hemorrhage and hyperthermia. A Thermacare convective warming system (Gaymar Industries, Orchard Park, New York, USA) was placed on the animals and they were covered with a Norm-O-Temp® heating blanket (Cincinnati Sub-Zero Products, Cincinnati, Ohio, USA) to bring their core temperature up to 108° F. The normal temperature for the swine is 101° - 103°F which is 2.4° - 4.4° higher than humans (Hannon, Bossone et al. 1990). This increase in core body temperature is consistent with the sign of hyperthermia often observed in the field and previously described (Ruttenber, Lawler-Heavner et al. 1997; Di Maio 2006). The temperature was chosen based on extrapolating from a human epidemiological study that found a temperature increase in deaths due to excited delirium of 104° or higher (Ruttenber, Lawler-Heavner et al. 1997).

Hemorrhage was induced by removing blood from the pig until a predetermined mean arterial pressure was reached. For the proposed effort, it was determined that a mean arterial pressure of 65 mmHg +/- 5 mmHg was sufficient in causing a stress without death from the blood loss (Swindle 2008). A catheter was inserted into the left femoral artery and blood was removed until the mean arterial pressure was reached. The shed blood was collected in a reservoir containing heparin for reinfusion as needed. For the duration of the study, a 65 +/- 5 mmHg pressure was maintained by reinfusion of heparinized shed blood. After hemorrhage, the animals were allowed to stabilize for at least 20 minutes if a CEW was to be applied.

Data Collection

The cardiac and pulmonary monitoring continued throughout the entire testing period and was averaged at baseline, after the stress in the experimental and control stress groups, before and after exposure(s) in the experimental and control CEW groups and at time points after the exposures. Blood was drawn (4.3 cc) from the carotid artery at baseline, after induction of the stress (where applicable), after exposure(s) (where applicable), prior to blood re-infusion (for the

single exposure group) and at one hour intervals for four hours after the exposure(s) to monitor various data. A total of 1.3 cc of blood was deposited into lithium-EDTA coated tubes to monitor potassium, pH, carbon dioxide pressure (pCO_2) oxygen pressure (pO_2), bicarbonate (HCO_3) and lactic acid using an i-Stat Digital Analyzer (Heska AG, Fribourg, Switzerland). The remainder of the arterial blood (3 cc) was put into EDTA coated collection tubes to examine changes in the cardiac marker troponin I using a RAMP System (Response Biomedical Corporation, British Columbia, Canada) for the multiple exposure group.

An additional 3 cc of blood was inserted into EDTA coated collection tubes to obtain values for epinephrine and norepinephrine. The blood was centrifuged for 15 minutes at 4°C, plasma was removed and aliqouted into polypropylene tubes (Sarstedt, Nümbrecht, Germany) that contained the preservative EGTA-glutathione (50 µl/ml of plasma). These samples were stored at - 20° C and shipped overnight to the Vanderbilt Diabetes Research and Training Center (Vanderbilt University, Nashville, Tennessee, USA) for analysis by High Performance Liquid Chromotography.

Application of CEW

Once a surgical plan of anesthesia was achieved, exposure(s) was/were applied to the animal by attaching probes from the TASER X26 (TASER International, Scottsdale, Arizona, USA) cartridge to the sternal notch and thorax. The standard pulse generated by the device during a normal application was applied. A total of three exposures were applied to each animal in a five seconds “on”, five seconds “off” pattern to evaluate the physiological effects of multiple exposures and a single exposure was applied to assess the effects of any CEW exposure in the stressful state.

Statistical Analysis

Blood gas measurements, cardiac index, heart rate, mean arterial pressure, troponin I (for 3 exposures), sodium, potassium, hematocrit, hemoglobin, and the catecholamines were analyzed using a Wilcoxon signed rank test to compare the baseline measurements with those taken at each time point. These values were evaluated for significance using either 1-tailed or 2-tailed test depending on having either a directional or non-directional hypothesis. The single exposure tests were run subsequent to the multiple exposure tests and were run with 1-tailed tests based on the revised hypotheses from the first tests. A Mann-Whitney U test was completed to determine whether there was a difference between the groups at each time point.

Results

The volume of blood draw to induce hypotension varied between experiments from 600 cc to 1100 cc (Table 1). The volume of blood that was required for reinfusion in the experimental group also varied from 30% to 100%. The amount of time to induce the hemorrhage and hyperthermia in the experimental group ranged from one to two hours with an average time of 1.5 hours (Table 1).

Table 1: Summary of stress induction.

Subject Number	Weight (kg)	Volume of Blood Drawn and Percent of TBV (cc)	Volume of Blood Reinfused (cc)	Time to Induce Stress (hours)
Control Stress Group				
2018	44	1100 (37%)	650	1
2017	52	800 (23%)	600	0.5
2019	45.6	900 (29%)	450	1
Experimental Group (Stress + 3 CEW Exposures)				
5001	46	750 (24%)	300	1.5
5000	47	900 (28%)	900	2
5004	46.8	900 (28%)	900	1
5006	46.4	750 (24%)	400	2
5005	48	600 (19%)	200	1
Control Stress Group				
2017	52	800 (23%)	600	0.5
6024	43	488 (16%)	430	1
6030	42.4	282 (10%)	282	2
6029	41	457 (16 %)	457	2.5
6031	43	606 (21%)	0	1.5
Experimental Group (Stress + 1 CEW Exposure)				
6038	43.4	665 (20%)	0	2
6039	40.4	586 (20%)	586	2
6043	45	733 (20%)	0	3
6042	38.6	275 (11%)	275	2
6047	43.8	672 (20%)	0	3

All of the animals in both control stress groups survived the study and were euthanized four hours after exposures. Three animals in the multiple exposure experimental group survived and were euthanized four hours after the exposures. Two animals survived 3 hours – 3.5 hours after the exposures. Four animals in the single exposure experimental group survived and were euthanized four hours after the exposure. One animal survived 2 hours after the exposure (Table 1).

Table 2: Summary of survival statistics.

Subject Number	Survival Status	Survival Time Post Exposures
Control Stress Group		
2018	Survived	NA
2017	Survived	NA
2019	Survived	NA
Experimental Group (Stress + 3 CEW Exposures)		
5001	Survived	4.0 H (euthanized)
5000	Non-survival	3.5 H
5004	Non-survival	3.0 H
5006	Survived	4.0 H (euthanized)
5005	Survived	4.0 H (euthanized)
Control Stress Group		
2017	Survived	NA
6024	Survived	NA
6030	Survived	NA
6029	Survived	NA
6031	Survived	NA
Experimental Group (Stress + 3 CEW Exposures)		
6038	Survived	4.0 H (euthanized)
6039	Non-survival	2.0 H
6043	Survived	4.0 H (euthanized)
6042	Survived	4.0 H (euthanized)
6047	Survived	4.0 H (euthanized)

Electrocardiogram

All baseline electrocardiograms for the experimental groups were normal (Figure 1). There were no arrhythmias after the hemorrhage and hyperthermia or immediately after the exposures. Heart rate increased after the stress (Figure 2) and again after the CEW exposures in all of the animals (Figure 3). Electrocardiograms data for the second part of this study (single exposure vs. control) are not presented here.

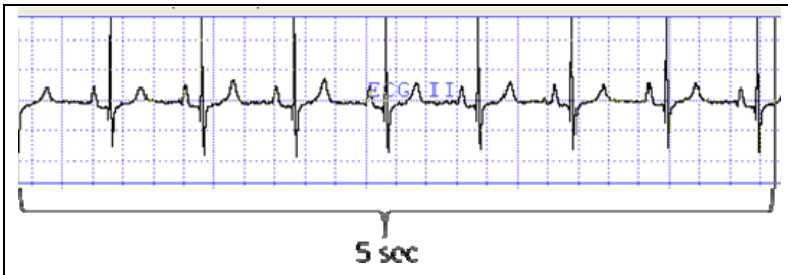


Figure 1: Normal rhythm

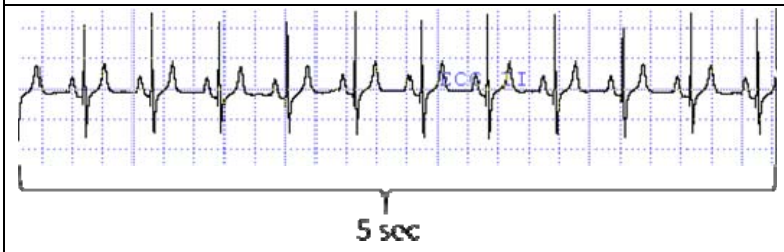


Figure 2: Rhythm after hemorrhage and hyperthermia

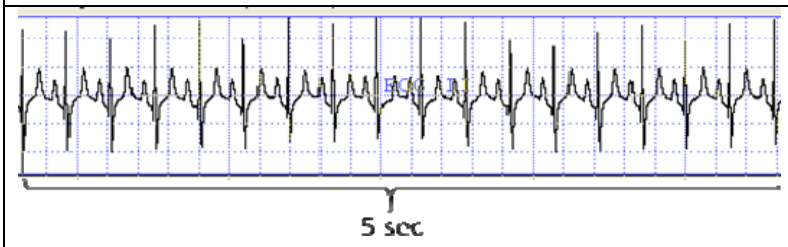
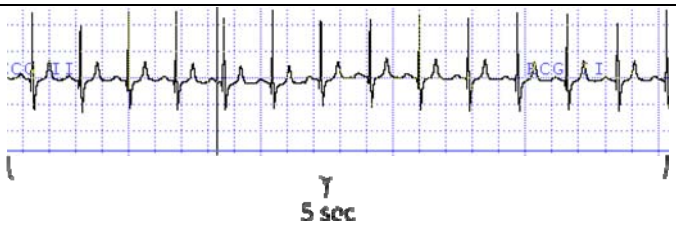
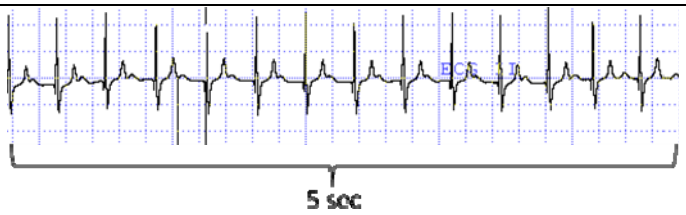
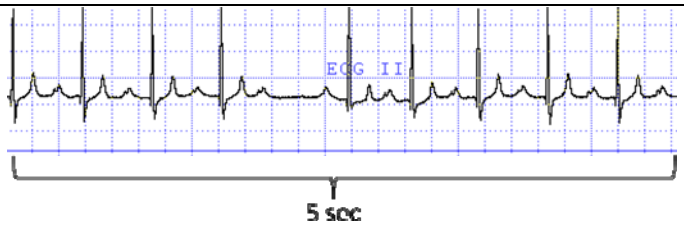


Figure 3: Rhythm after three exposures.

The three animals that survived the multiple exposures exhibited several changes and arrhythmias after the exposures. A more flattened p-wave occurred one hour after the exposures in one of the animals (Figure 4). An AV conduction delay (Figure 5) and several non-conducting p-waves also occurred after the exposures in two of the animals (Figure 6). One subject (5006) did not have any arrhythmias.

Subject Number	ECG Recording
5001	 **Figure 4: Flattened P-wave**
5001	 **Figure 5: AV conduction delay**
5005	 **Figure 6: AV conduction block**

One animal (5005) in the survival group had periods of sinus tachycardia complicated with intermittent episodes of complete AV block (third degree). This animal never lost sinus rhythm; however, the impulse was not conducted to the ventricles therefore, there was an absence of QRS complexes and no arterial pressure waves (Figure 7).

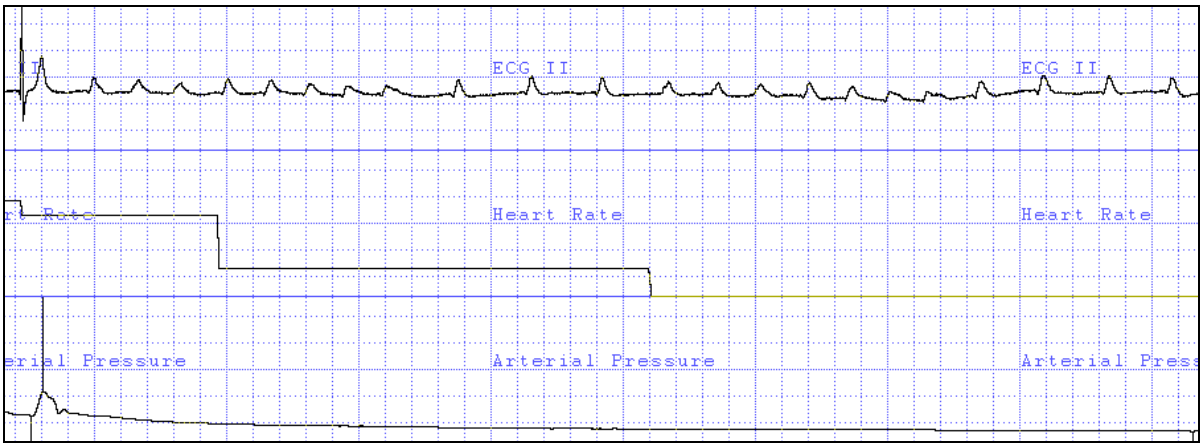


Figure 7: Example of complete AV block lasting 8.2 seconds.

The ECGs of the subjects that died were normal at baseline and they did not exhibit any arrhythmias immediately after the hemorrhage or the three CEW exposures. Approximately four minutes after the exposures, one animal (5000) had several premature supra-ventricular contractions with aberrant conduction (Figure 8- a). The other subject (5004) exhibited a taller, more peaked t-wave after the exposures along with a wider, flatter p-wave (Figure Figure 8– b), when compared with the baseline recording (Figure 8- a). Sixty-nine minutes after the exposures, subject number 5000 began to exhibit AV conduction delays which are p-r intervals greater than 200 ms. This animal then exhibited bouts of supraventricular tachycardia, AV conduction blocks (Figure 8 - b) and finally ventricular tachycardia (Figure 8 – c) and death. The other subject (5004) also had AV conduction blocks, premature ventricular contractions, ventricular tachycardia, and periods of asystole prior to death.

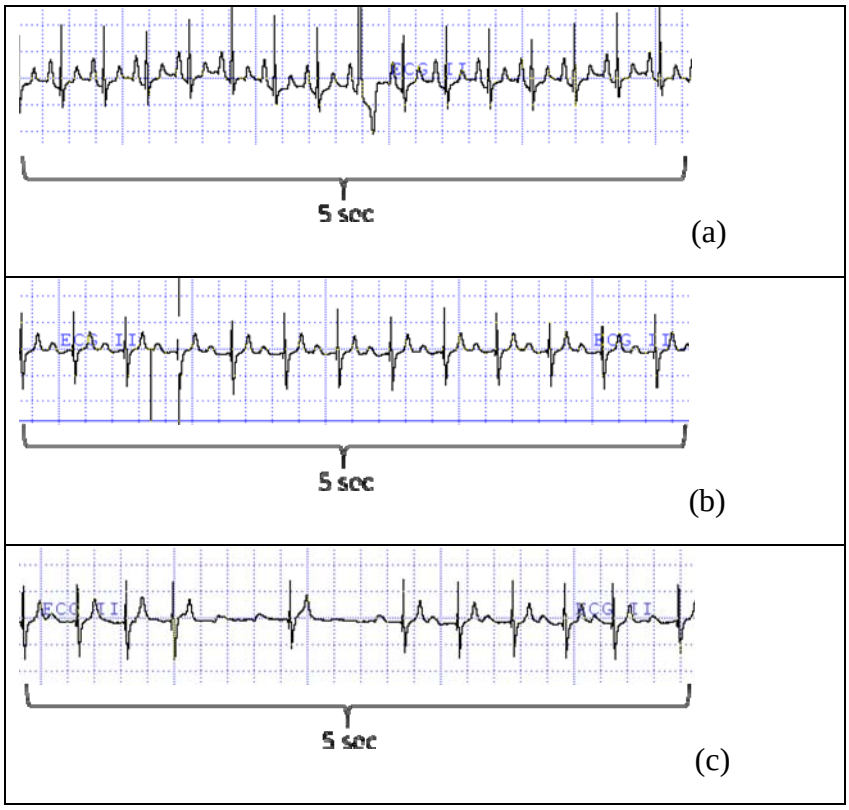


Figure 8: Examples of changes in ECG and arrhythmias after TASER X26 exposure for subject 5000 including (a) a premature supra-ventricular contraction, (b) AV conduction delay (p-r interval > 200 ms) and (c) AV conduction block

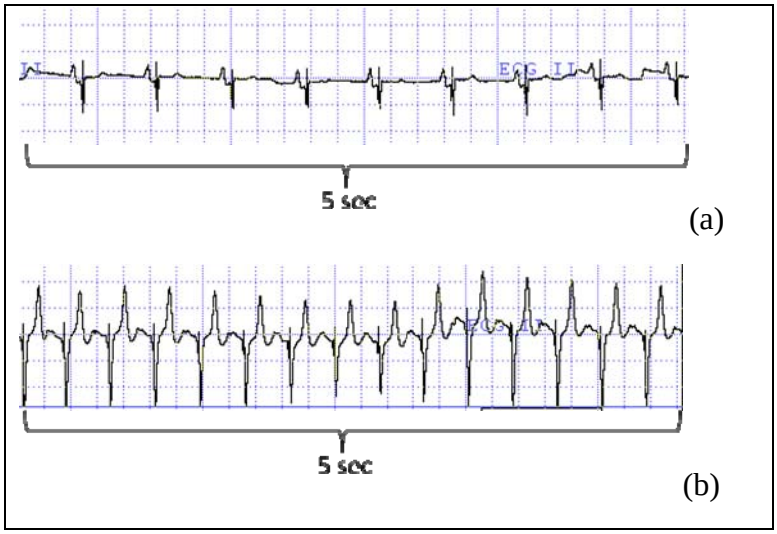


Figure 9: Comparison of (a) baseline ECG with (b) an ECG immediately after TASER X26 exposure for subject 5004

Results from the multiple exposure group vs. controls

Troponin I and Catecholamines

Troponin I was evaluated for statistical significance using an exact 1-tailed test. There was no significant difference ($p > 0.05$) between the baseline measurement and the measurements taken at all other time points for the experimental group (Figure 10). There was also no significant difference between the experimental group and the control group. All values for the experimental group were 0.0 ng / ml at baseline. This value increased slightly in two animals to 0.1 ng / ml and 0.12 ng / ml. The baseline value of one animal in the control group was 0.78 ng / ml. This value remained elevated throughout the experiment and increased to a maximum value of 0.92 ng / ml three hours after the exposures.

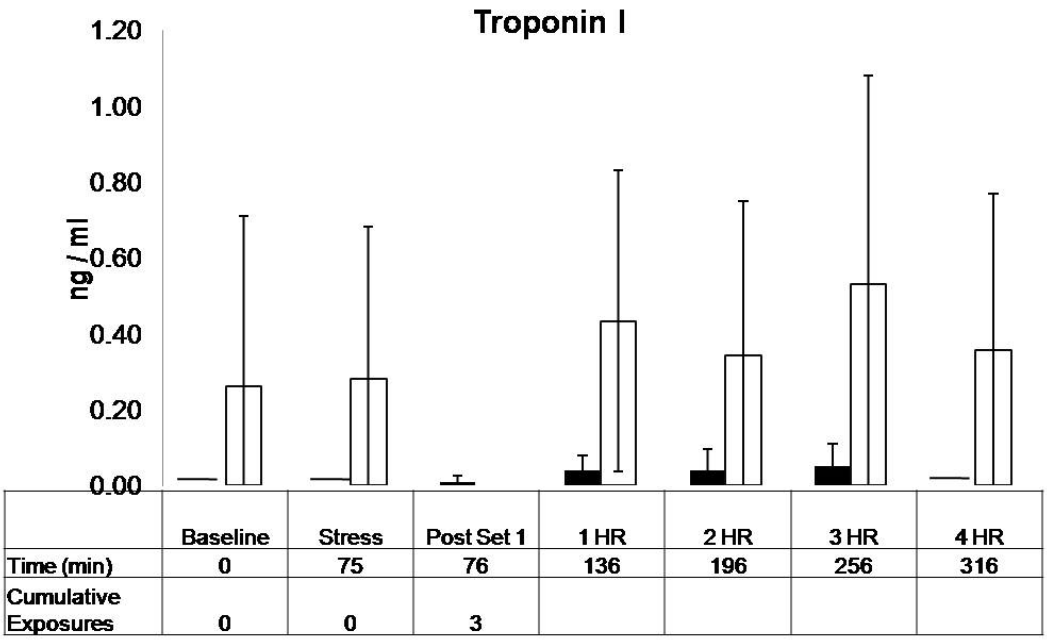
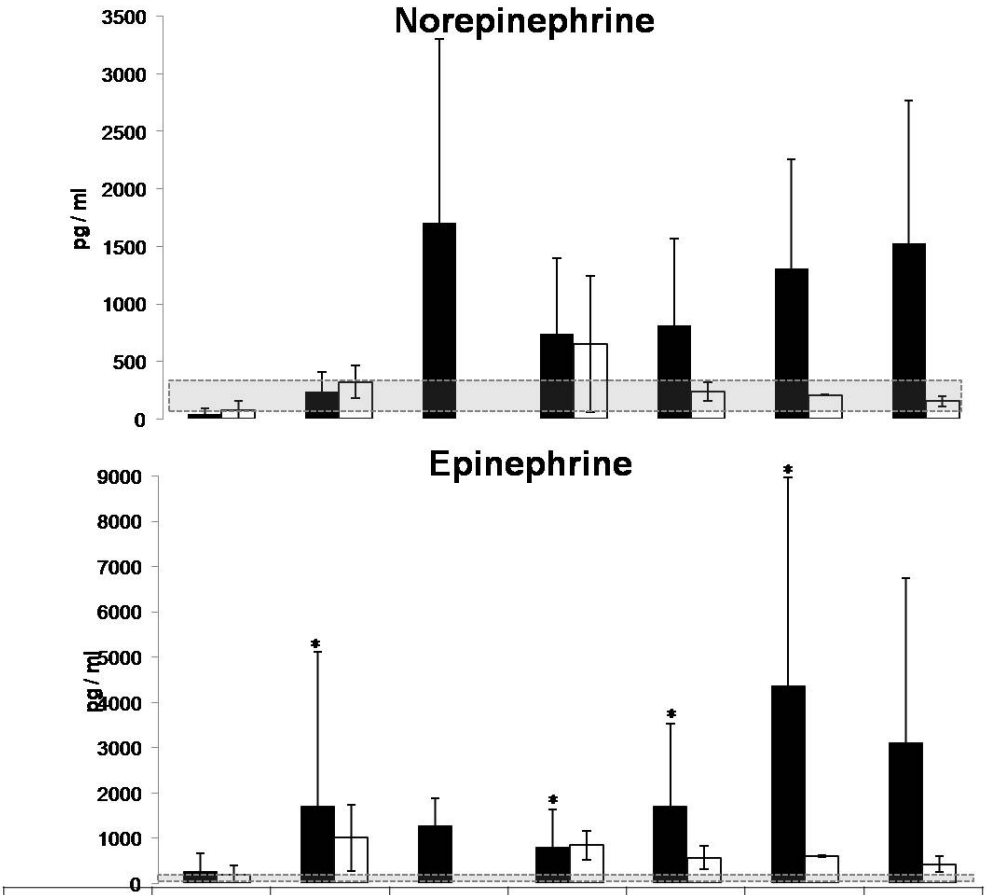


Figure 10: Values of troponin I at baseline (time 0), after stress, three exposures and at rest four hours (60 min intervals) after the exposures for the experimental group (black bars) and control stress only group (white bars).

Catecholamines were evaluated for statistical significance using the exact 1-tailed test. All baseline values recorded for norepinephrine were lower than or within the normal range (53 – 332 ng / ml) previously reported in swine (Hannon, Bossone et al. 1990). Two animals in the experimental group had a value that was higher than the normal range (20 – 132 ng / ml) for epinephrine in swine, including one animal with a value of 990 ng / ml (Figure 11). All subsequent values for this animal were much higher than the others, creating a large standard deviation.

Epinephrine increased significantly ($p = 0.031$) in the experimental group after the hyperthermia and hemorrhage was completed (Figure 11). These values exhibited a slight decrease after the

exposures and then increased significantly one hour after the exposures and remained significantly elevated for three hours after the exposures. Norepinephrine increased after the hyperthermia and hemorrhage and again after the exposures, although these changes were not significant. These values decreased one hour after the exposures and then increased slightly each hour after. The difference between the stress only group and the experimental group was not significant at any time point for either epinephrine or norepinephrine.



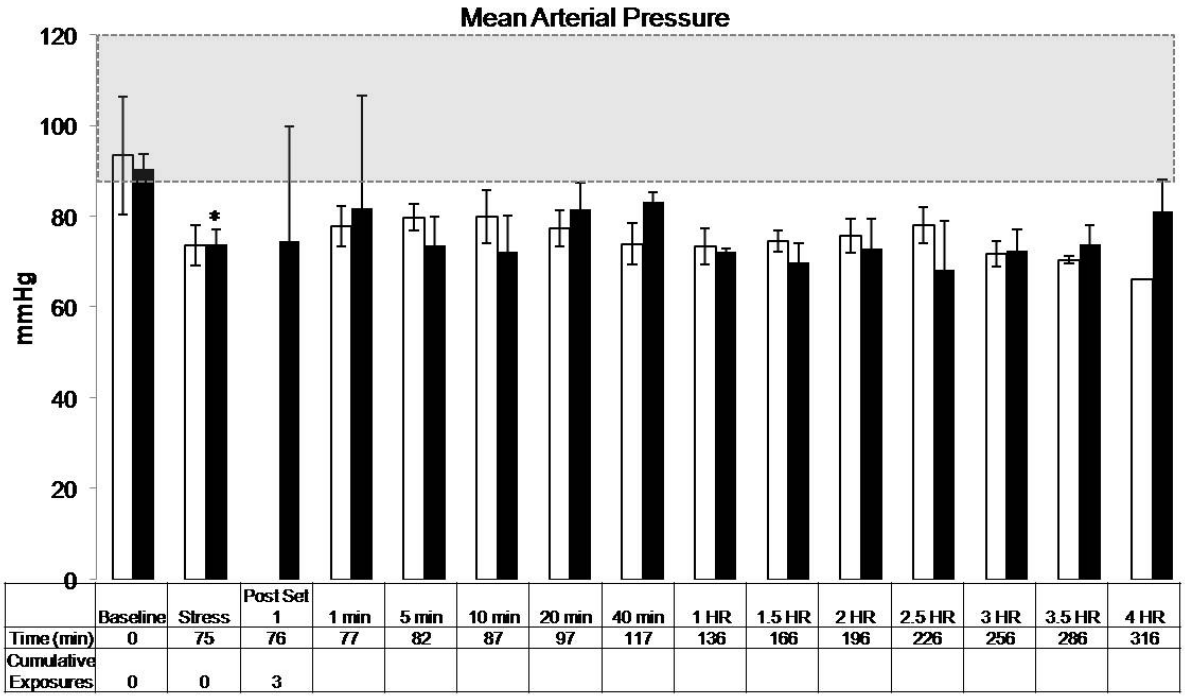
	Baseline	Stress	Post Set 1	1 HR	2 HR	3 HR	4 HR
Time (min)	0	75	76	136	196	256	316
Cumulative Exposures	0	0	3				

Figure 11: Values of norepinephrine and epinephrine at baseline (time 0), after stress, three exposures and at rest four hours (60 min intervals) after the exposures for the experimental group (black bars) and control stress only group (white bars). Shaded area represents normal values from swine (Hannon, Bossone et al., 1990) * Significantly elevated from baseline ($p < 0.05$).

Hemodynamic Measurements

Pressure was evaluated for statistical significance using the exact 1-tailed test after the stress. It was hypothesized that this value would decrease compared to the baseline values. For all other time points, the values were evaluated using an exact 2-tailed test because it was not clear whether it would increase or decrease. The baseline values were within the normal range

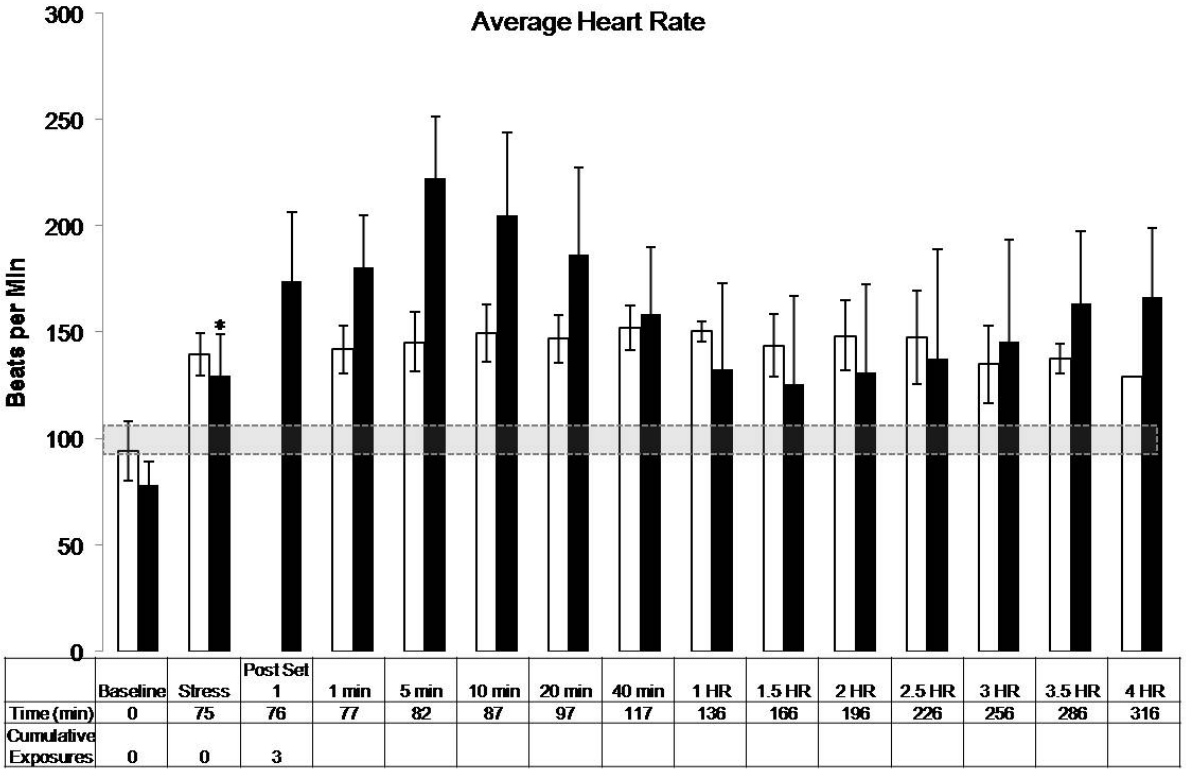
previously reported for swine (Hannon, Bossone et al. 1990). Pressure decreased significantly ($p = 0.031$) after the hemorrhage and hyperthermia (Figure 12) to a value lower than normal. Pressure remained lower than the normal range for the remainder of the experiment. There was no significant difference between the baseline value and any other time point. There was also no significant difference between the control and experimental group at any time point.



	Baseline	Stress	Post Set 1	1 min	5 min	10 min	20 min	40 min	1 HR	1.5 HR	2 HR	2.5 HR	3 HR	3.5 HR	4 HR
Time (min)	0	75	76	77	82	87	97	117	136	166	196	226	256	286	316
Cumulative Exposures	0	0	3												

Figure 12: Values of mean arterial pressure at baseline (time 0), after stress, three exposures and at rest four hours after the exposures for the experimental group (black bars) and control stress only group (white bars).

Heart rate was evaluated for statistical significance using the exact 1-tailed test after the stress and immediately after the exposures. It was hypothesized that this value would increase compared to the baseline values. For all other time points, the values were evaluated using an exact 2-tailed test because it was not clear whether it would increase or decrease. The values recorded at baseline were lower than the normal range previously reported for swine (Hannon, Bossone et al. 1990). Heart rate was significantly elevated ($p = 0.031$) from the baseline value after the hemorrhage and hyperthermia (Figure 13) to a value that was higher than normal. Although the average heart rate recorded after the exposures was higher than the heart rate after the stress, this value was not significantly elevated from baseline due to the large standard deviation. Heart rate continued to increase (although not significantly) for five minutes after the exposures to a maximum value of 222 beats per minute. The difference between the stress only group and the experimental group was significant five minutes after the exposures ($p = 0.036$). Heart rate remained elevated above normal in both the test and control stress only group for the entire experiment.



	Baseline	Stress	Post Set 1	1 min	5 min	10 min	20 min	40 min	1 HR	1.5 HR	2 HR	2.5 HR	3 HR	3.5 HR	4 HR
Time (min)	0	75	76	77	82	87	97	117	136	166	196	226	256	286	316
Cumulative Exposures	0	0	3												

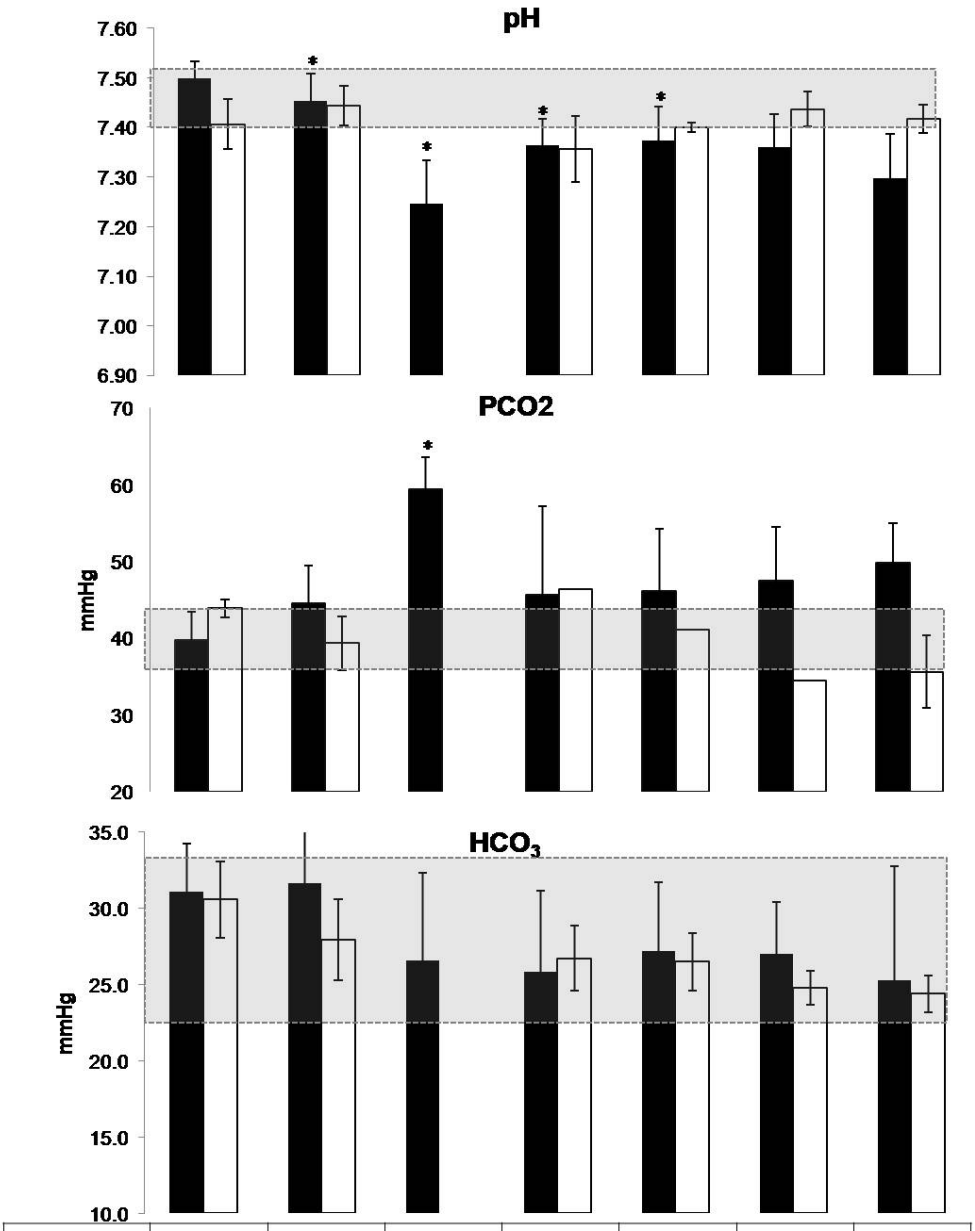
Figure 13: Heart rate at baseline (time 0), after stress, three exposures and at rest four hoursafter the exposures for the experimental group (black bars) and control stress only group (white bars). Shaded area represents normal values reported for swine (Hannon, Bassone et al., 1990)

Arterial Blood Gas and Potassium

All baseline values were in the normal range previously reported for swine for pH, pCO_2 and HCO_3 (Hannon, Bossone et al. 1990). An exact 1-tailed test statistic was used to evaluate pH and pCO_2. pH has been shown to decrease and pCO_2 to increase during exposure to CEWs (Jauchem, Sherry et al. 2006; Esquivel, Dawe et al. 2007; Jauchem, Cook et al. 2007). The pH decreased significantly after the hemorrhage and hyperthermia and again after the exposures ($p = 0.31$) to a value that is lower than normal (Figure 8.10). This value remained significantly lower than the baseline value for two hours after the exposures. The pCO_2 values increased significantly ($p = 0.31$) after the exposures to an average value of 59 mmHg, which is higher than the normal range. This value decreased after the exposures and was not significantly elevated from baseline one hour after the exposures, although it remained elevated above normal for the remainder of the study. There was a significant difference between the groups for pH at the baseline value only ($p=0.036$). There was no significant difference between the groups for pCO_2 at any time point.

An exact 2-tailed test statistic was used to evaluate HCO_3 (bicarbonate). Bicarbonate was not evaluated in previous studies, therefore, there was no directional hypothesis associated with this measurement. There were no significant changes in bicarbonate at any time during this study.

This value did decrease during the experiment; however, it remained in the normal range previously reported for swine (Hannon, Bossone et al. 1990). There was no significant difference between the experimental group and the control group at any time point.



	Baseline	Stress	Post Set 1	1 HR	2 HR	3 HR	4 HR
Time (min)	0	75	76	136	196	256	316
Cumulative Exposures	0	0	3				

Figure 14: Values of pH, CO2 and HCO3 at baseline (time 0), after stress, three exposures and at rest four hours (60 min intervals) after the exposures for the experimental group (black bars) and control stress only group (white bars).

Lactate was evaluated for significance using the exact 1-tailed statistic. Lactate has increased in previous studies involving CEWs (Jauchem, Sherry et al. 2006; Esquivel, Dawe et al. 2007; Jauchem, Cook et al. 2007). All values for lactate at baseline were within the normal range previously reported in swine (Hannon, Bossone et al. 1990). Lactate increased significantly after the hemorrhage and hyperthermia and increased to 7.9 mM / L after the three exposures (Figure 15). This value remained significantly elevated from baseline and was higher than normal for two hours after the exposures. There was no significant difference between the baseline value and those recorded three or four hours after the exposures. The difference between the stress only group and the experimental group was significant at baseline and two hours after the exposures ($p = 0.036$).

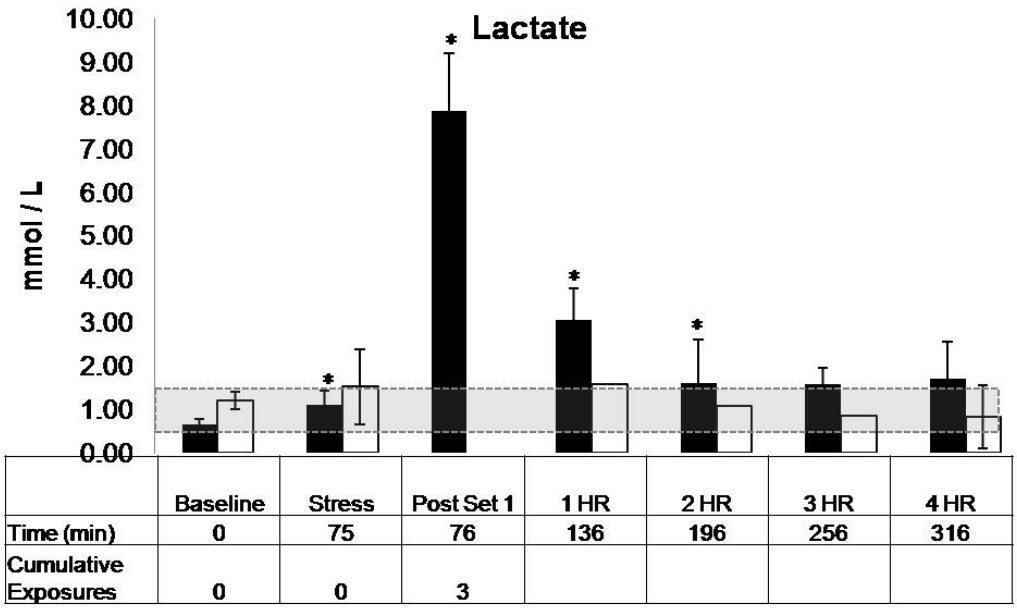


Figure 15: Values of lactate at baseline (time 0), after stress, three exposures and at rest four hours (60 min intervals) after the exposures for the experimental group (black bars) and control stress only group (white bars).

The exact 2-tailed test statistic was used to determine significance for potassium, as it was uncertain as to whether it would increase or decrease. The baseline values recorded for potassium were within the normal range previously reported in swine for the experimental group (Hannon, Bossone et al. 1990). Although, no changes in potassium were statistically significant, potassium increased after the hyperthermia and hemorrhage to an average value of 6.4 mM / l which is a higher than normal value (Figure 16). This value increased slightly after the exposures. Two hours after the exposures, the average potassium values were 7.6 mM / l – the highest value recorded for the experiment. There was no significant difference between the experimental and control groups at any time point.

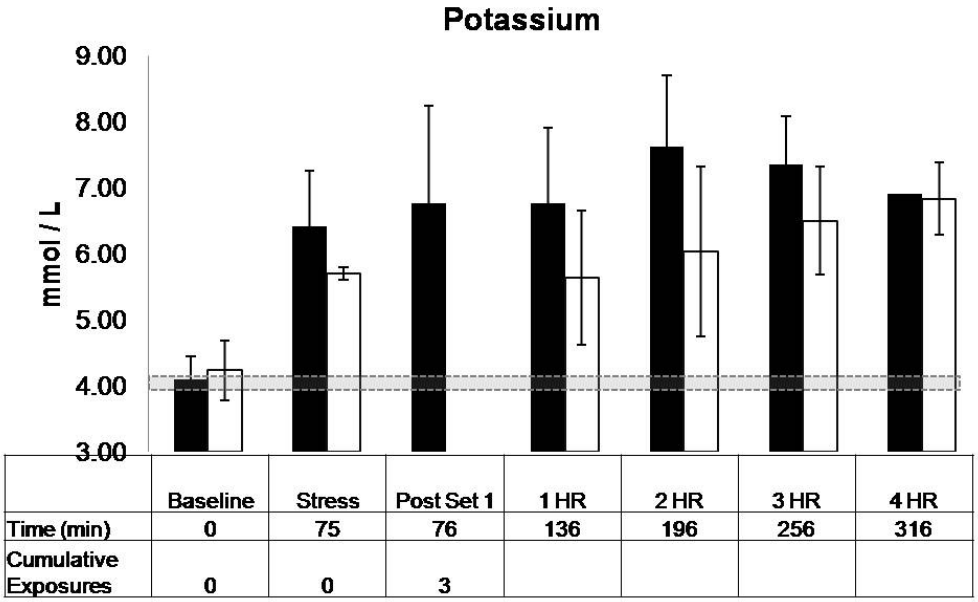


Figure 16: Values of potassium at baseline (time 0), after stress, three exposures and at rest four hours (60 min intervals) after the exposures for the experimental group (black bars) and control stress only group (white bars).

Results from the single exposure group vs. controls

Electrolytes and Catecholamines

The exposure group did not demonstrate any statistically significant change in potassium levels post-exposure (Figure 17). Sodium was found to be significantly lower in the exposure group at all time points except for baseline and the 4th hour (Figure 18). The exposure group did not demonstrate any statistically significant change in either of the catecholamine levels post-exposure (Figure 19 & Figure 20).

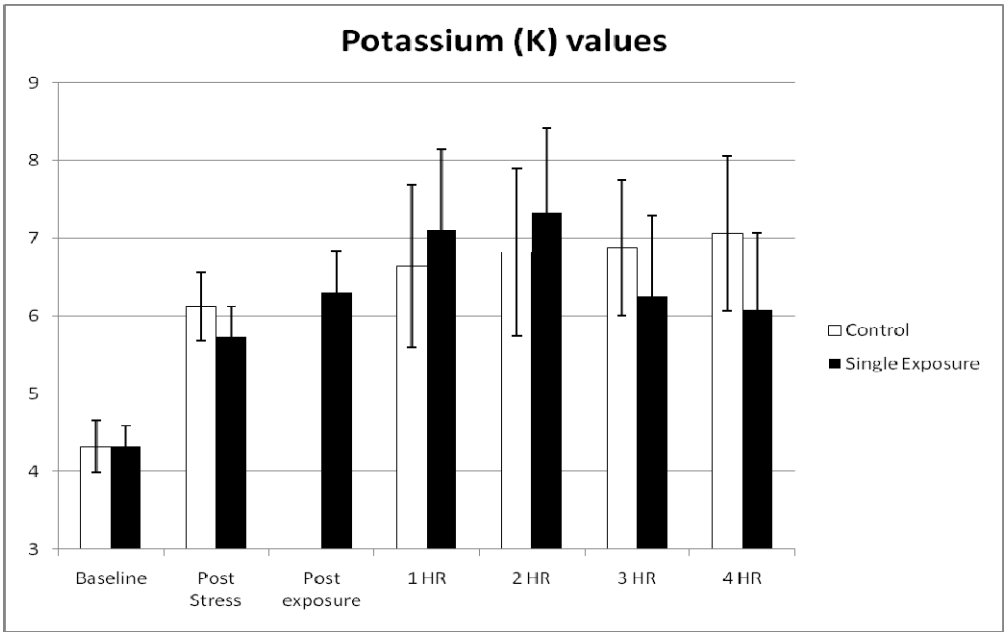


Figure 17: Average Potassium values in the blood for the control and Taser groups.

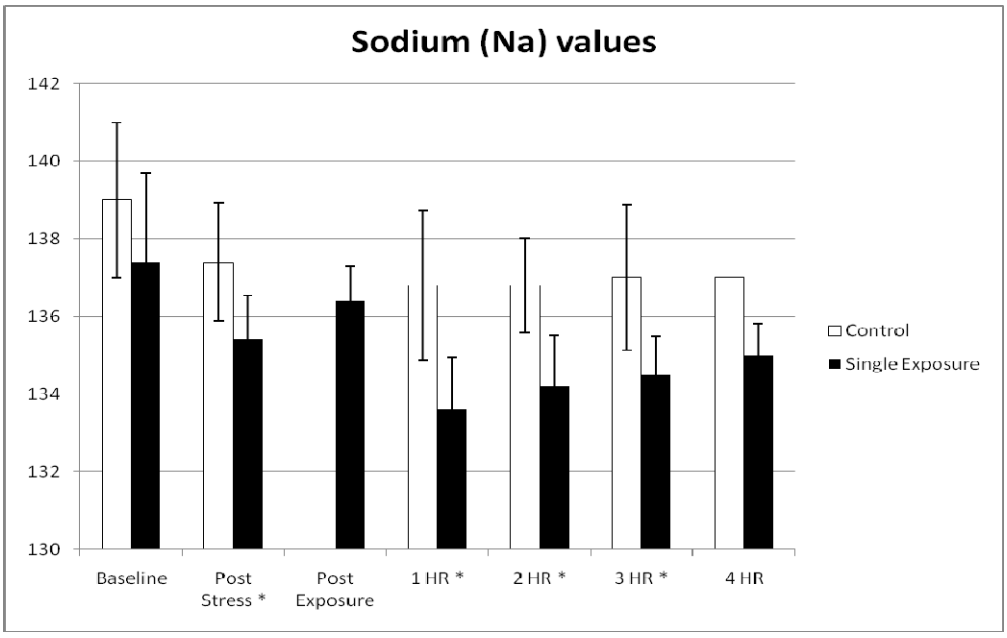


Figure 18: Average Sodium values in the blood for the control and Taser groups.

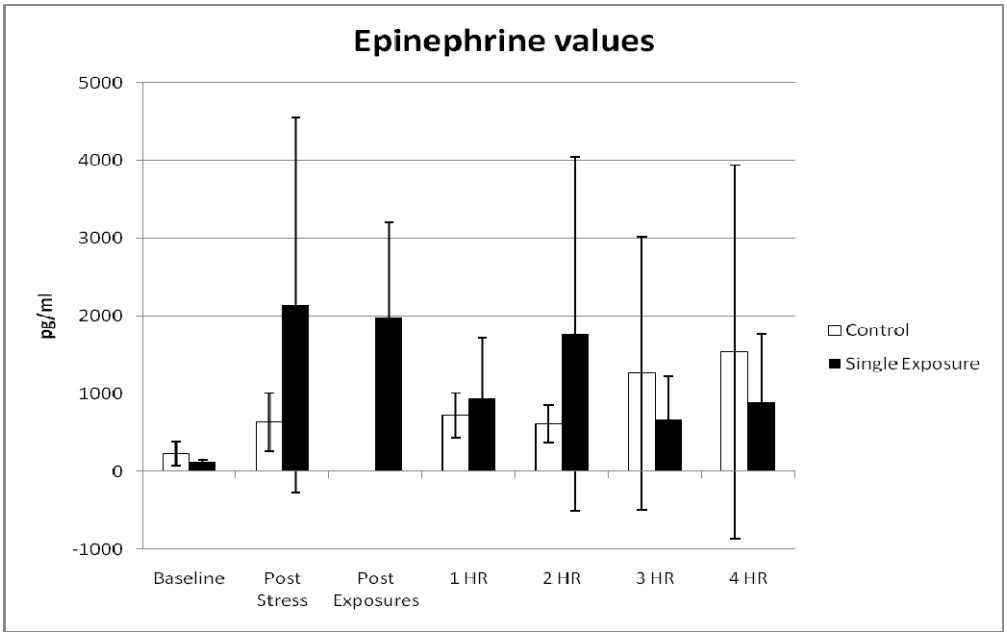


Figure 19: Average Epinephine values in the blood for the control and the Taser specimens.

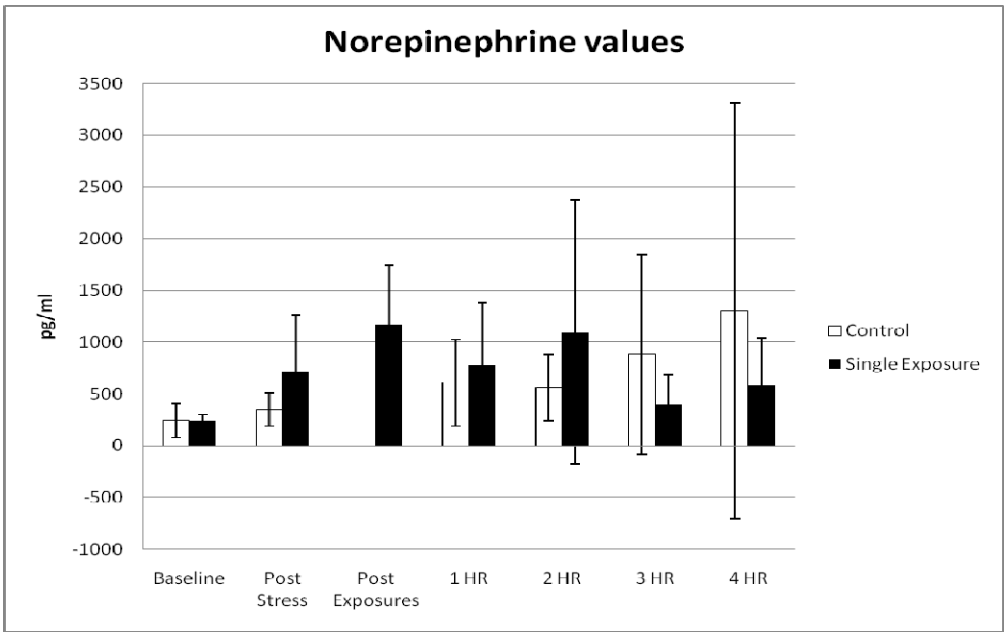


Figure 20: Average Norepinephine values in the blood for the control and the Taser specimens.

Blood gases, buffers and pH

The HCO_3 levels were found to be significantly higher in the exposure group at all time points except for the 2nd hour (Figure 21). The exposure group did not demonstrate any statistically significant change in pO_2 levels post-exposure (Figure 22). The pCO_2 levels were found to be significantly higher in the exposure group at the 2nd hour (Figure 23). The lactate levels were found to be significantly higher in the exposure group at the 1st and 2nd hours (Figure 24). The exposure group did not demonstrate any statistically significant change in pH levels post-exposure (Figure 25).

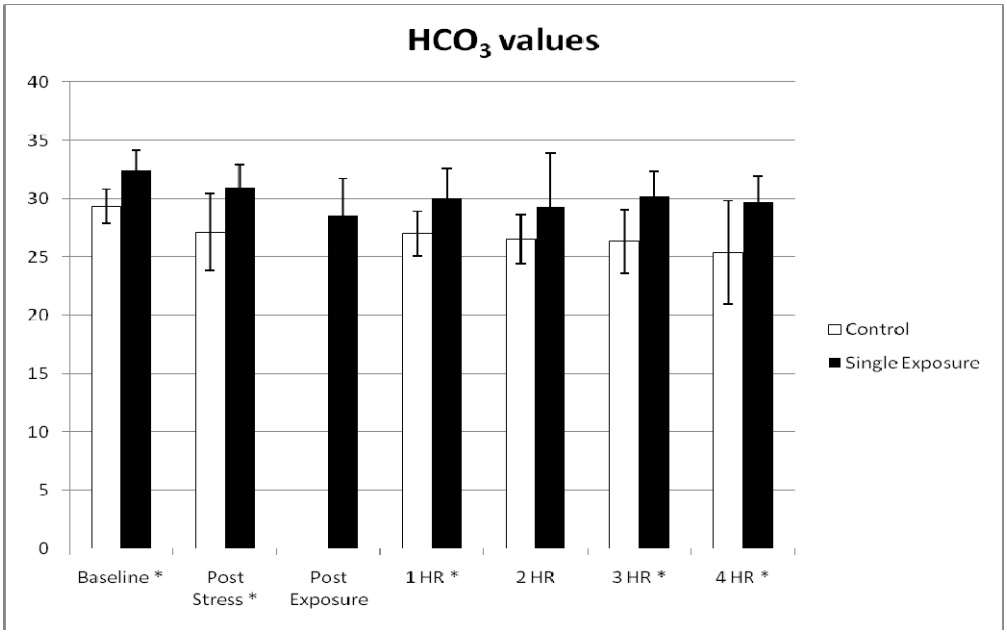


Figure 21: Average HCO3 values in the blood for the control and Taser groups

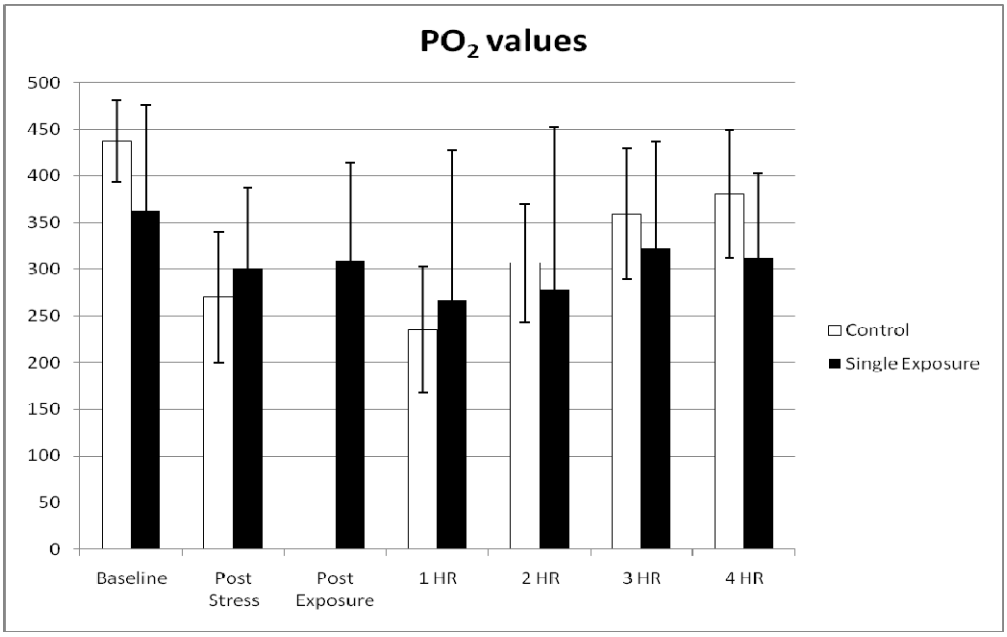


Figure 22:Average PO2 values in the blood for the control and Taser groups

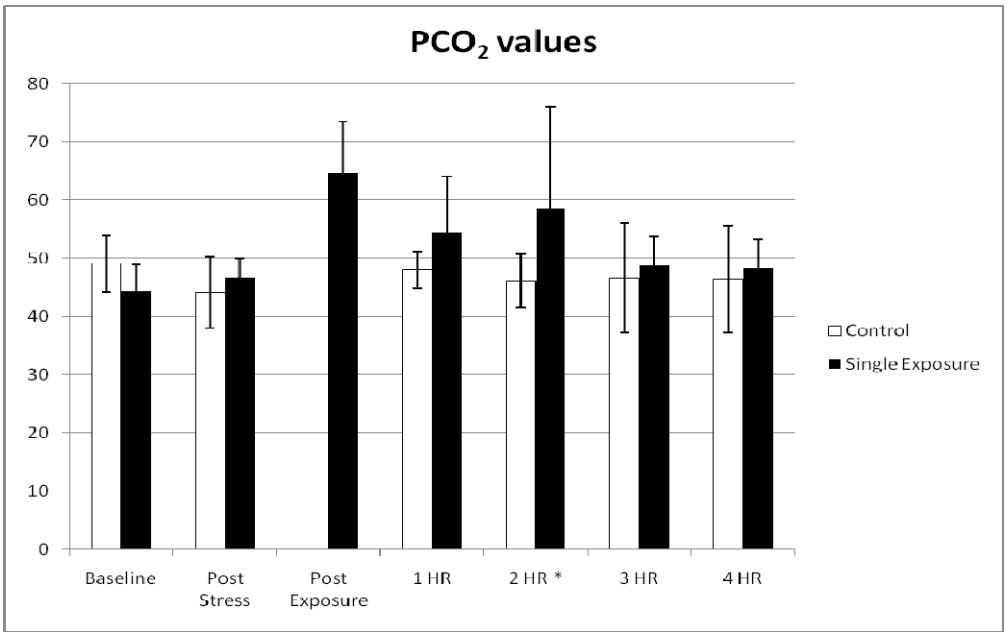


Figure 23:– Average PCO2 values in the blood for the control and Taser groups

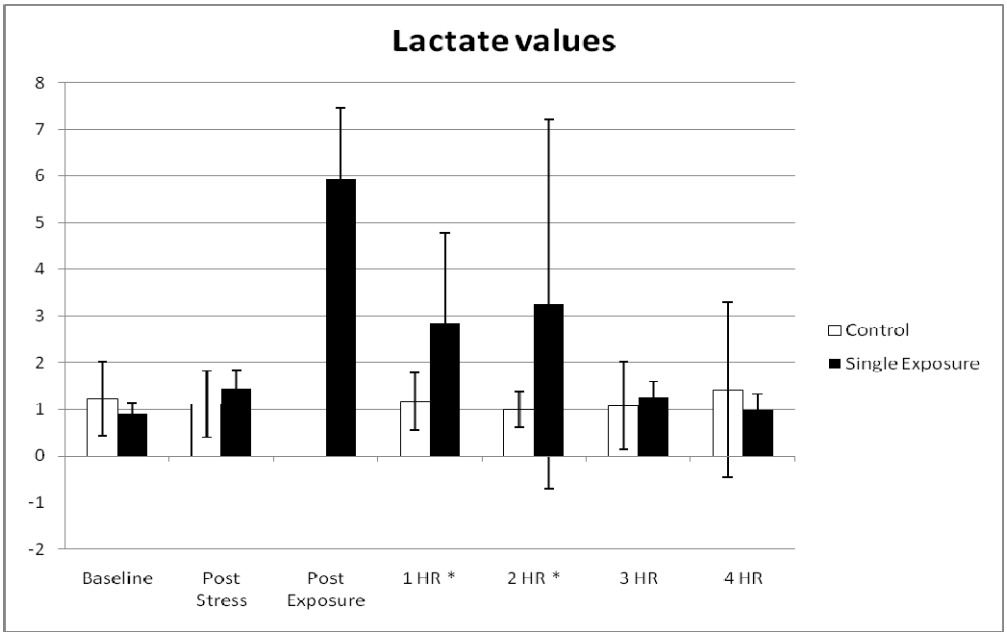


Figure 24: Average Lactate values in the blood for the control and Taser groups

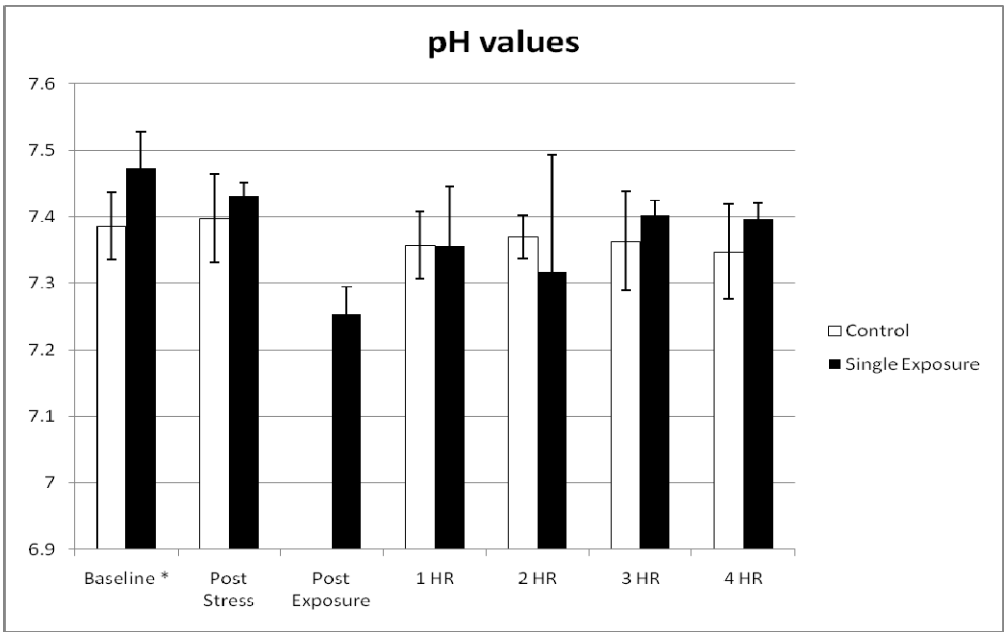


Figure 25: Average pH values in the blood for the control and Taser groups

The cardiac output, hematocrit, hemoglobin, heart rate and mean arterial pressure levels for the exposure group were not found to be significantly different from the stress only group at any time points during the testing \. The temperature levels were found to be significantly lower in the exposure group at Baseline, Post Stress and after the 1st hour (Figure 31).

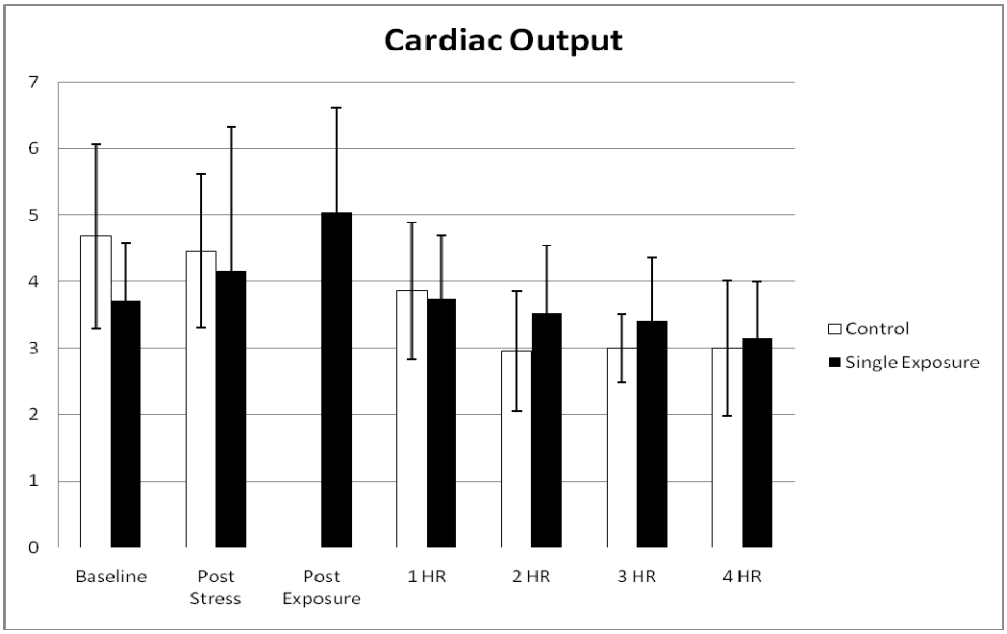


Figure 26: Average Cardiac Output values in the blood for the control and Taser groups

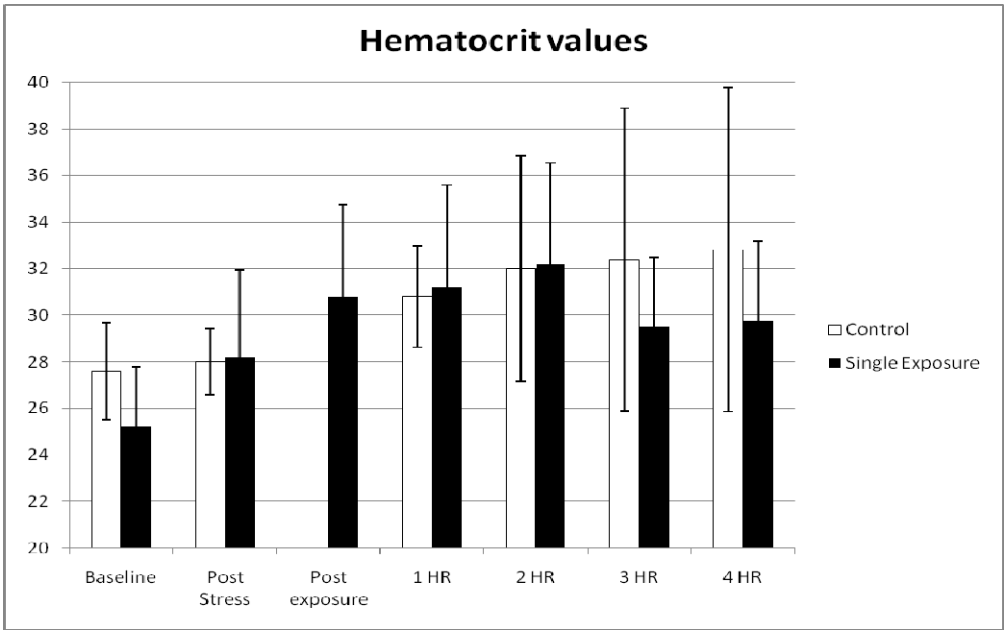


Figure 27: Average Hematocrit values in the blood for the control and Taser groups.

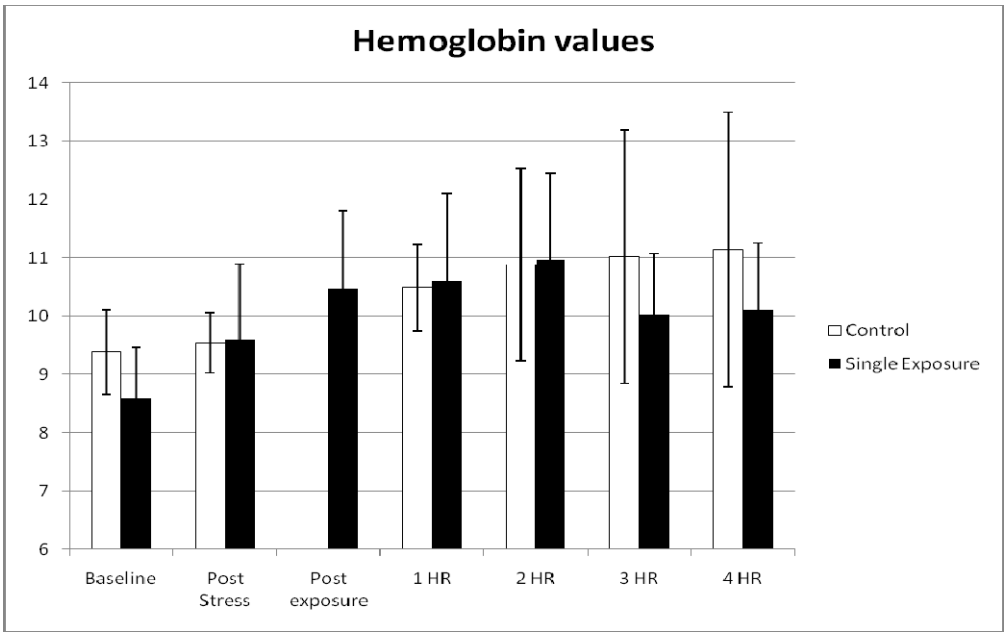


Figure 28: Average Hemoglobin values in the blood for the control and Taser groups.

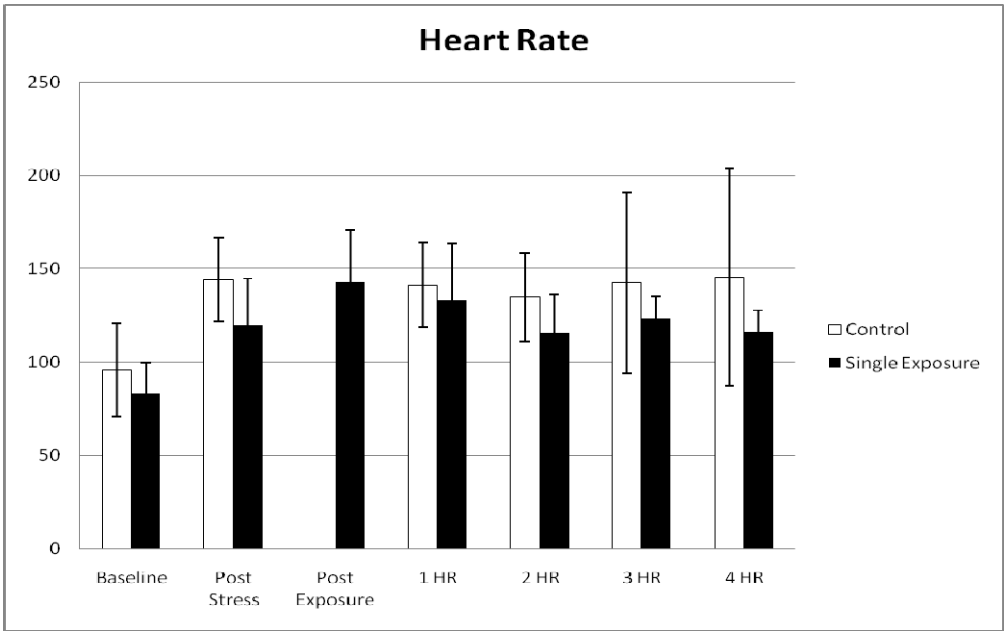


Figure 29: Average Heart Rate values for the control and Taser groups

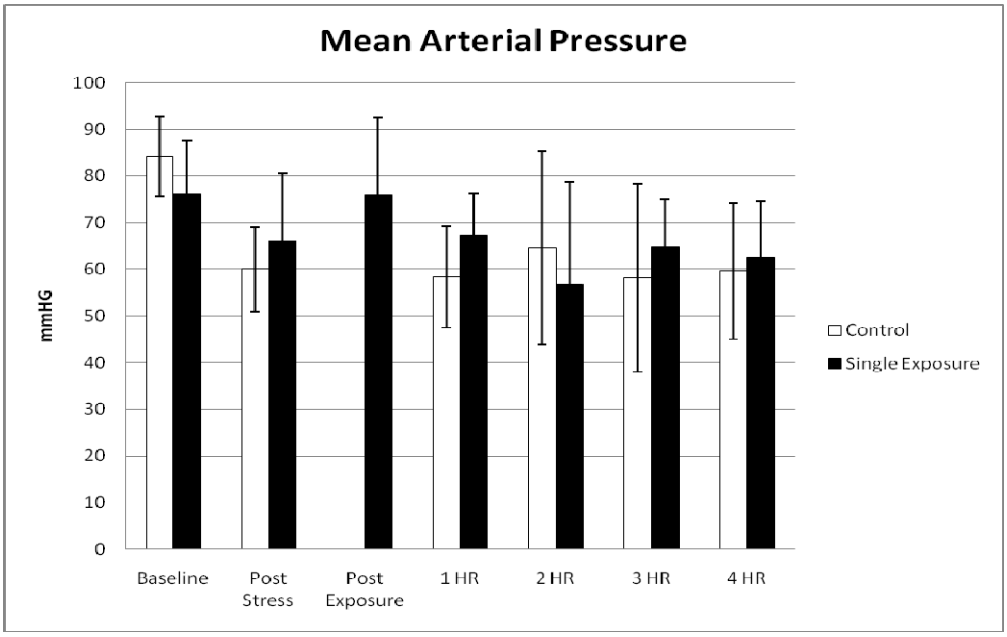


Figure 30: Average Mean Arterial Pressure values in the blood for the control and Taser groups

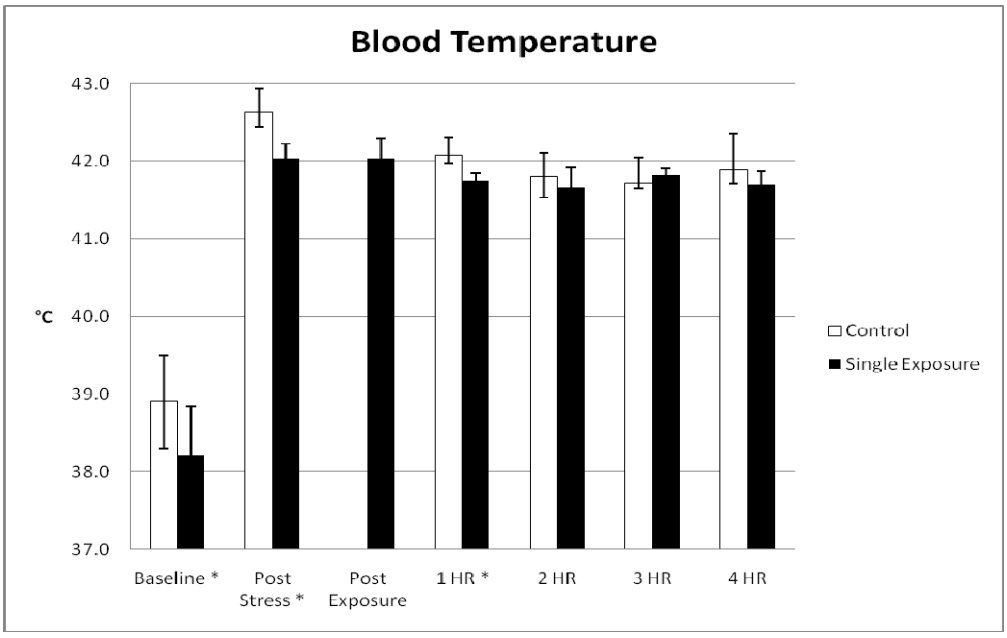


Figure 31: Average core body temperature for the control and Taser

Summary

This research demonstrates a unique investigational model to evaluate the combined effects of a physiologically induced stress and CEW exposure. The hemorrhage and hyperthermia completed for this study caused a stress on the animals which resulted in an increase in heart rate and catecholamines, decrease in mean arterial pressure, decrease in pH and increase in lactate. All five animals in the control hemorrhage and hyperthermia group survived the four hour time period after the induction of stress. One of the five animals did experience serious arrhythmias (2nd degree AV block) four hours after the hemorrhage.

The main implication for this research is the ability to use these findings to guide a policy related to the use of CEWs in given operational scenarios. Such information can be useful to law enforcement agencies when making decisions related to the deployment of CEWs. In addition, knowledge related to the physiological effects of CEW use in compromised individuals is useful to emergency medical personnel for determination of proper medical treatment and the development of treatment protocols.

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