CLASSICALLY CONDITIONED CHANGES IN HEART RATE AND BLOOD PRESSURE BASED ON ELECTRIC SHOCK OR AMMONIA-FUMES REINFORCEMENT

by

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An examination was made in the present experiment of the relationship between classically conditioned changes in heart rate and blood pressure and of the effects of two different types of reinforcing stimuli on the development of these conditioned responses. A 2 x 2 factorial design was employed involving four groups of 12 rats each. Two of the groups were given 30 paired presentations of the conditioned stimulus and the unconditioned stimulus, and the other two groups received 30 explicitly unpaired presentations of the conditioned and unconditioned stimuli. The unconditioned stimulus employed was either electric shock that produced increases in heart rate and blood pressure, or ammonia fumes that elicited decreases in heart rate and increases in blood pressure. The principal findings were that for both unconditioned stimuli the direction of the conditioned heart rate response was decelerative and matched that of the heart rate orienting response elicited by the conditioned stimulus prior to conditioning. There was little evidence that the direction of the

conditioned heart rate response was influenced by the direction of the unconditioned heart rate response. Similarly, the blood pressure conditioned response was virtually identical to the blood pressure orienting response originally produced by the conditioned stimulus. Both of these responses contained two components, a short latency increase in pressure followed by a longer latency decrease in pressure. As was true for heart rate, the conditioned blood pressure response did not appear to be affected by the unconditioned blood pressure response. The failure of the type of unconditioned stimulus to influence the conditioned heart rate and blood pressure responses was not consistent with the traditional stimulus-substitution theory of conditioning. Instead, the similarity between the orienting responses and conditioned responses supported a sensitization hypothesis of conditioning according to which the conditioned response is thought to develop from the orienting response.

TABLE OF CONTENTS

	page
ACKNOWLEDGEMENTS	i
LIST OF TABLES	ii
LIST OF FIGURES	iii
INTRODUCTION	1
Definition of classical conditioning	1
History of conditioned heart rate	3
Relationship of blood pressure and heart rate	5
Review of studies of conditioned heart rate and blood pressure	
Humans	8
Monkeys	11
Ewes	13
Dogs	14
Rabbits	25
Cats	31
Rats	32
Objectives of present study	37
METHODS	38
Subjects	38
Apparatus	38
Procedure	42
Blood pressure recording system	45
RESULTS	52
Preconditioning trials with the CS alone	52
Acquisition	59
Unconditioned responses	78
DISCUSSION	87
Principle findings	87
Orienting responses	88
Conditioned responses	90
Theories of conditioning	100
Unconditioned responses	104
SUMMARY AND CONCLUSIONS	109
REFERENCES	111
APPENDIX	120

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LIST OF TABLES AND APPENDIX

Table 1: Spearman rank-order correlations between heart rate and blood pressure during preconditioning trials. 58

Table 2: Mean blood-pressure changes during the three periods of the CS averaged across blocks of acquisition trials. 69

Table 3: Spearman rank-order correlations between heart rate and blood pressure during the three periods of the CS. 76

Table 4: Spearman rank-order correlations between unconditioned heart rate and blood pressure during six periods following the US. 86

Appendix A: Summary of the studies indicating the directions of unconditioned and conditioned heart rate and blood-pressure changes. 120

LIST OF FIGURES

Figure 1: A diagram of the circulatory system in the rat tail. 43

Figure 2: A flow chart indicating the blood-pressure recording system. 46

Figure 3: A graph of the relationship between pulses/sec and blood pressure. 49

Figure 4: Mean CS minus pre-CS heart rate and blood-pressure responses during each of the three periods of the CS averaged across five blocks of two preconditioning trials each. 53

Figure 5: Mean pre-CS baseline heart rate and blood pressure averaged across five blocks of two preconditioning trials each. 56

Figure 6: Mean CS minus pre-CS heart rate and blood-pressure responses during the entire CS averaged across five blocks of six acquisition trials each. 60

Figure 7: Mean CS minus pre-CS heart-rate responses during each of the three CS periods averaged across five blocks of six acquisition trials each. 63

Figure 8: Mean CS minus pre-CS blood-pressure responses during each of three CS periods averaged across five blocks six acquisition trials each. 66

Figure 9: Polygraph record of the heart rate and blood pressure reactions of a rat in the ammonia experimental group on a paired CS-US trial. 71

Figure 10: Polygraph record of the heart rate and blood pressure reactions of a rat in the ammonia control group on an unpaired trial. 72

Figure 11: Mean pre-CS baseline heart rate and blood pressure averaged across five blocks of six acquisitions trials each. 74

Figure 12: Mean post-US minus pre-CS heart rate and blood pressure reactions to electric shock averaged over three blocks of 10 acquisition trials each. 79

Figure 13: Mean post-US minus pre-CS heart rate and blood pressure responses to ammonia fumes averaged over three blocks of 10 acquisition trials each. 82

INTRODUCTION

In the course of his investigations on the digestive processes of dogs, for which he received a Nobel Prize in 1904, I. P. Pavlov noticed that stimuli which regularly preceded the appearance of food came to elicit salivary and gastric secretions. Systematic study of the salivary portion of this reaction, which Pavlov termed "psychic" secretion, began with his classical experiments in 1927. In these studies the dog was trained to stand passively on a table in a special room designed to keep extraneous noises from reaching the dog. A metronome or tuning fork was sounded, and after a 7 or 8-sec delay, a small portion of meat powder was delivered to the dog. Initially, the sound did not elicit salivation, although it was apparent that the act of eating the meat powder was accompanied by copious salivation. After several pairings of the sound with meat powder, salivation was observed when the sound was presented by itself.

The procedure in the experiment just cited represents one example of the classical conditioning paradigm. More generally, classical conditioning consists of a set of experimental operations involving an unconditioned stimulus (US) which reliably produces an unconditioned response and a conditioned stimulus (CS) that does not initially produce the "to be conditioned" response. Typically, the CS (e.g. metronome) and US (e.g. meat powder) are presented repeatedly with the CS preceding the US, and a response similar to the unconditioned response develops to the CS. This newly developed

response is termed the conditioned response.

Other physiologists working in Pavlov's era were familiar with the appearance of "psychic" secretions, but they ignored the phenomenon because such a response appeared to be related to the animal's thoughts and as such was not subject to physiological examination (Gantt, 1937). To Pavlov, on the other hand, "psychic" secretions revealed adaptive behavior on the part of the animal to its external and internal environments. Furthermore, the fact that these anticipatory secretions occurred demonstrated to him that classical conditioning could be used as an objective and powerful tool for investigating the functions of the cerebral cortex. As a result of his systematic investigations on salivation, Pavlov proposed a stimulus-substitution theory of classical conditioning (Kimble, 1961) in which the CS came to substitute for the US eliciting a response similar to that produced by the US.

Prior to his studies on conditioned salivary responses, Pavlov spent ten years, from 1880 to 1890, examining the cardiovascular system of dogs. He measured the heart-rate reactions of dogs to many different kinds of external stimulation and found that they displayed changes in heart rate to almost all of the stimuli that were presented. Apparently, because of this sensitivity, Pavlov later chose not to study cardiovascular responses in classical conditioning situations.

In spite of the fact that Pavlov restricted his investigations to the salivary response, his early work stimulated a number of

American investigators to attempt to condition other response systems. During the last 50 years, classical conditioning experiments have been carried out on a wide range of different types of responses including leg flexions, eye blinks, galvanic skin potentials and various cardiovascular reactions such as heart rate, blood pressure, and contractility. The results of such studies have been employed in theoretical formulations dealing with such diverse areas as learning, motivation, and emotion. Recently, a considerable amount of work has been carried out in an attempt to specify those processes and mechanisms controlling classically conditioned changes in the cardiovascular system. Broadly viewed, the present experiment was concerned with the question of the particular pattern of cardiovascular activity that occurs during classical aversive conditioning.

Perhaps the first report of a classically conditioned change in cardiac activity was made by Sherrington (1900). He observed that the heart rate of a dog decreased from 180 to 54 beats per minute to the vibratory sound of an inductorium (CS) which had been used to administer shock (US). Sherrington interpreted his data within the framework of the James-Lange Theory of Emotion (James, 1900) and viewed this heart rate change as being an autonomic component of anxiety.

A few years later, John B. Watson (1916) measured the heart rate responses of a single human in a classical conditioning setting. Although changes in heart rate apparently occurred to the CS, Watson was not convinced that they were conditioned because of the presence

of respiratory reactions on the electrocardiogram tracings.

As cited by Beier (1940), classically conditioned changes in heart rate were studied in an unpublished MS thesis by Shipley (1929). Using a buzzer CS and an electric shock US, Shipley found that, after being paired with the US, the buzzer alone produced a change in heart rate. Unfortunately, no details on the nature or direction of the heart-rate change were published. In a brief abstract it was reported by Ssorokhtin, Turgel and Minut-Ssorokhtin (1934) that decreases in heart rate were conditioned to a bell CS that was paired with pressure on the eye (oculocardiac reflex) as the US.

One of the first detailed accounts of classically conditioned heart rate was reported by Gantt and Hoffman (1940) using three dogs. All of the dogs displayed conditioned increases in heart rate to a CS signalling food reinforcement. Furthermore, the magnitude of the conditioned heart-rate response was approximately the same as that of the unconditioned reaction to the food.

Since these early studies on classical conditioning of heart rate, other cardiovascular responses such as blood pressure (Girden, 1942), blood flow (Smith and Steppins, 1965), contractile force (Obrist, Howard, Lawler, Sutterer, Smithson and Martin, 1972) and cardiac output (Bergamaschi and Longoni, 1973) have been measured in classical conditioning situations. Moreover, a number of experiments have appeared dealing with those factors that influence the direction, magnitude and performance of classically conditioned heart-rate responses (Cohen and MacDonald, 1974; Fitzgerald and

Teyler, 1970; Lacey and Lacey, 1974; Obrist, Howard, Lawler, Galosy, Meyers and Gaebelein, 1974; and Schneiderman, 1974).

One question that has received considerable attention in this area is whether heart rate can be conditioned directly or whether it is secondary to other changes in the cardiovascular system. For example, it is well known that variations in heart rate can be initiated by: (1) circulating agents in the blood such as catecholamines and hormones; (2) stretching of atrial muscle (Bainbridge reflex); (3) changes in pH, pO_2 and pCO_2, all of which are monitored by chemoreceptors; and (4) changes in blood pressure (Guyton, 1976). Of these four factors, blood pressure has received the most attention.

The possibility that changes in blood pressure might mediate, or at least influence, heart-rate conditioned responses is of greatest concern in subjects in which the direction of the heart-rate response is decelerative. This includes a number of species such as rabbits (Yehle, Dauth, and Schneiderman, 1967), cats (Hein, 1969), and rats (Fitzgerald, Martin, and O'Brien (1973) as well as humans (Obrist, Wood, and Perez-Reyes (1965). In such subjects, elevations in blood pressure could trigger heart-rate decelerations through the activation of the baroreceptors located principally in the carotid sinus and aortic arch. Among other things, baroreceptor stimulation leads to increased vagal firing which in turn produces cardiodeceleration (Guyton, 1976). The broad objective of the present experiment was to provide evidence on the relationship between conditioned cardiodecelerative heart-rate responses and

changes in blood pressure in rats.

Before surveying the literature dealing with conditioned heart-rate and blood-pressure reactions, it may be helpful to outline the procedures that have been used to measure these responses. Typically, both responses have been measured in terms of difference scores which are computed by subtracting the amount of activity (i.e. heart rate in beats per minute or blood pressure in mm Hg) during a prestimulus interval from the amount of activity during the stimulus interval. On the basis of this computation, a positive score reflects an increase in activity to the stimulus, and a negative score a decrease in activity. If the amount of activity during the stimulus is uniformly above the prestimulus baseline level, the response is characterized as a monophasic increase. Likewise, if the amount of activity is consistently below the baseline level, the response is called a monophasic decrease. In some situations a stimulus may elicit a reaction having both increase and decrease components. In this case, the response is termed biphasic.

Although heart rate and blood pressure have been examined in a wide variety of conditioning situations using several different species of subjects, no single set of procedures has been employed to evaluate the possible interrelationships between the two responses. Those procedures most frequently employed include: (1) statistical evaluations of correlations between heart rate and blood pressure during various portions of the conditioning sessions, (2) determinations of whether a change in one response on any given trial

was accompanied by a change in the other response, (3) examinations of whether heart rate and blood-pressure responses developed or extinguished at different rates, and (4) tests of the effects of various pharmacological blocking agents on each of the responses. Drugs which have been used in this latter capacity include parasympathetic and sympathetic blocking agents. Examples of parasympathetic blocking agents include atropine sulfate and methylatropine, both of which antagonize vagal influences on the heart (Goodman and Gilman, 1970). Sympathetic blocking agents are subdivided into alpha- and beta-adrenergic antagonists. Alpha-adrenergic receptors, responsible for vasoconstriction of the arterioles, are inhibited by phentolamine and dihydroergotoxine mesylate, whereas beta-adrenergic receptors, located on the heart, are blocked by propranolol. Another drug sometimes employed is six-hydroxydopamine (6-OHDA) which attenuates general sympathetic activity by destroying both alpha- and beta-adrenergic terminals (Clark, Laverty, and Phelan,1972).

Although the present experiment was concerned primarily with studying classically conditioned changes in heart rate and blood pressure, those investigations in which only blood pressure was measured were also given attention in reviewing the literature. These experiments were included to provide a complete documentation of what is currently known about conditioned blood pressure.

It is well known that the directions of conditioned heart rate and blood pressure reactions often vary with the type of species being investigated. Moreover, the directions of the responses may

even vary within the same species, depending upon the particular experimental procedures that are employed. The following studies were grouped according to the type of species that was used in the hope that this would aid in clarifying possible mechanisms that might be involved in the control of heart rate and blood pressure conditioned reactions.

Humans. In an early experiment, Beier (1940) measured blood pressure, heart rate, and respiration in three humans using a buzzer CS and exercise on a bicycle ergometer as a US. He defined conditioning on the basis of a difference between responses to the CS on trials administered prior to conditioning and responses to the CS after it was paired with the US during acquisition training. One subject displayed a conditioned biphasic (decelerative-accelerative) heart rate response, another a monophasic cardiodeceleration, and the third gave evidence of conditioned premature ventricular contractions. For all three humans blood pressure conditioned responses were described as "disturbances" consisting of rapid increases and decreases in pressure. No clear evidence of respiratory conditioning was reported. Although Beier did not compare heart rate and blood pressure changes, it would appear that the blood pressure conditioned reactions were more consistent than the heart rate responses.

Obrist, Wood, and Perez-Reyes (1966) used a CS+ vs CS- differential conditioning procedure and examined the cardiovascular and respiratory responses of 60 humans divided into various groups. The

US, either a 1.88 or a 3.86 ma electric shock to the finger tip, was paired with a CS+ (a red light) on 36 trials, whereas a CS- (blue light) was never paired with shock. It was found that a biphasic (accelerative-decelerative) heart-rate response developed to CS+. However, based on the results of a previous study (Wood and Obrist, 1964) it was concluded that only the decelerative component of the response represented conditioning. The blood-pressure conditioned response took the form of a monophasic increase which reached a peak of 1.9 mm Hg systolic and 1.2 mm Hg diastolic (means of 5 subjects). These values were obtained by subtracting the blood-pressure response to CS- from the response to the CS+. Tests were made of the effects of various autonomic blocking agents on the heart rate and blood-pressure reactions. Atropine abolished the cardiodecelerative portion of the heart-rate response in all subjects. However, in those subjects receiving the high intensity US, the cardiodeceleration was replaced by cardioacceleration. Hydergine, an alpha-blocking agent, attenuated conditioned blood-pressure increases but not conditioned heart-rate decelerations. On the basis of these results, it was argued that conditioned heart-rate decreases were primarily dependent on increased vagal activity, and that sympathetic influences were prevalent only when an intense shock was used. In addition, conditioned heart-rate decreases did not appear to depend on pressor responses. Further evidence of the independence of conditioned heart rate and blood pressure was provided by the fact that decelerative heart-rate responses were observed in the absence

of increases in blood pressure. Moreover, the magnitude of the conditioned heart-rate reactions did not correlate with the magnitude of conditioned blood-pressure responses.

In a differential conditioning study involving 55 undergraduates, DeLeon (1972) used a light-on plus cuff inflation as a CS+ and a light-off plus cuff inflation as a CS-. The CS+ was paired with an electric shock US applied to the lower leg. Although heart rate, blood pressure and respiration were recorded, only blood-pressure data were reported. It was found that the direction of the conditioned blood-pressure responses matched that of the unconditioned reaction, with both responses being increases in pressure. The mean CS+ minus CS- difference in systolic pressure was 2 mm Hg as measured in 28 students at the end of three days of conditioning. Although DeLeon suggested that correlation analyses involving heart rate and respiration may help to clarify the possible role of these responses in the occurrence of blood-pressure responses, he did not report evidence of this kind.

In a recent study by Whitehead, Lurie, and Blackwell (1976), six human subjects were given classical conditioning trials of a tone CS paired with a body-tilt US. Four other humans received unpaired presentations of the CS and US as a conditioning control for pseudo-conditioning or sensitization. The body-tilt US consisted of rotating supine subjects on a motor-driven tilt table to a head-down position of 15 degrees with respect to the horizontal. This maneuver elicited an unconditioned decrease in blood pressure through stimu-

lation of baroreceptors in the carotid sinus. Whitehead et al. found that the direction of the conditioned blood-pressure response that developed to the CS was also a decrease in pressure, and that it occurred within five trials. The magnitude of this response averaged across 6 subjects and 7 test trials was 4.35 mm Hg. On the final test trial, the mean decrease in pressure was 12 mm Hg. It should be noted that this conditioned decrease in pressure was different in direction from the conditioned increases in pressure obtained in other studies involving humans (Obrist, Wood, and Perez-Reyes, 1965; De Leon, 1972). In both of these other studies, electric shock was used as the US. In the De Leon experiment, it was reported that the shock US elicited an unconditioned increase in blood pressure. The fact that the conditioned and unconditioned responses in the De Leon experiment were both increases, whereas the two responses were both decreases in the Whitehead et al. study, is consistent with the Pavlovian stimulus-substitution theory of classical conditioning.

Monkeys. A conditioned emotional response (CER) paradigm was used by Brady, Kelly, and Plumlee (1969) to study conditioned blood pressure and heart rate in five rhesus monkeys. In this paradigm, a click CS that had been paired with a foot-shock US was presented while the animals were lever pressing for food reinforcement. All of the monkeys showed complete suppression of lever pressing to the CS, and in most cases, the suppression developed before conditioned cardiovascular changes. Heart rate and blood-pressure conditioned responding was complex. On early conditioning trials, the animals

showed cardiodecelerations in heart rate, whereas on later trials, cardioaccelerations occurred. Three monkeys exhibited no changes in blood pressure in the presence of heart-rate decreases during early trials, but blood-pressure increases accompanied heart-rate increases on later trials. Heart rate appeared to condition more rapidly than blood pressure suggesting that the two responses may be established independently. Blood-pressure responses were quite variable across trials and from animal to animal with the magnitude of systolic-pressure changes ranging from 5 to 20 mm Hg. To account for the relatively small magnitude blood-pressure conditioned responses, the authors suggested that homeostatic mechanisms may have stabilized and minimized blood-pressure changes to compensate for the larger fluctuations in heart rate.

Eight monkeys were used by Klose, Augenstein, Schneiderman, Manes, Abrams, and Bloom (1975) in a differential conditioning study involving blood pressure and heart rate. Orienting responses to the tone CSs during preconditioning trials consisted of blood-pressure increases unaccompanied by any consistent heart-rate changes. Conditioned increases in both heart rate and blood pressure occurred to the CS+. The unconditioned responses elicited by the tail-shock US were also increases in heart rate and blood pressure. The mean systolic and diastolic blood pressure changes of eight monkeys to the CS+ were 12 mm Hg and 10 mm Hg, respectively. Comparable values for the CS- were 3 and 2 mm Hg, respectively, for systolic and diastolic pressure. The authors noted that conditioned blood-pressure

responses often occurred in the absence of conditioned heart-rate responses.

Ewes. Heart rate, blood pressure, respiration, skeletal motor movement, and electroencephalographic (EEG) activity of 14 ewes were studied by Naitoh (1971). He used a click CS and two USs, one of which was a strong shock (670v, 100 ma) and the other a mild shock. Both shocks were delivered through a small, stainless-steel grid implanted beneath the periosteum. Based on behavioral and EEG data, Naitoh claimed that the strong shock was capable of eliciting electroconvulsive seizures. The ewes were divided in several groups including: (1) pairing the click CS with the mild shock, (2) pairing the CS with the strong shock, and (3) pairing the CS with the mild shock and then presenting the strong shock 1 min later. The latter condition was meant to provide an assessment of whether electroconvulsive siezures induced by the strong shock were capable of blocking cardiac and motor conditioning.

Conditioning was defined on the basis of a statistically significant difference between activity before the CS (baseline) and activity during the CS. A specific conditioning control procedure was not employed. The groups receiving the mild shock or the mild shock with the delayed strong shock displayed conditioned increases in heart rate and blood pressure. The magnitude of the blood-pressure change was 10 mm Hg which represented the mean response of three ewes after 11 paired trials. These changes matched the direction of unconditioned heart rate and blood-

pressure changes. Also present was a conditioned motor response (forelimb movement) which developed later than conditioned cardiovascular responses. In the group receiving the delayed strong shock, the motor conditioned response was attenuated but conditioned heart rate and blood-pressure reactions were not. No conditioned responses were noted in the group given just the strong shock as the US. The authors concluded that the strong electroconvulsive shock was not an adequate US for the development of conditioned responses, either motor or autonomic, but that such shocks were capable of impairing conditioned motor responses. No attempt was made to study possible interactions between heart rate and blood-pressure conditioned responses.

Dogs. Probably the most commonly studied species in classical conditioning experiments of heart rate and blood pressure has been the dog. Pavlov (1879) was one of the first to determine the normal blood-pressure level of conscious dogs and to study the effects of appetitive and aversive stimuli on blood pressure (Gantt, 1960). One of the earliest full-scale studies of conditioned blood pressure was reported by Girden (1942). He examined the blood-pressure responses to a spot-light CS and an electric-shock US in five dogs paralyzed with erythroidine. The original or orienting response to the CS on preconditioning trials was an increase in blood pressure which habituated upon repeated presentations of the CS. The unconditioned response to the shock US was also an increase in pressure. Conditioned increases in blood pressure were evident after only eight trials in one dog. Of the remaining animals,

the slowest dog required 12 trials to display a blood pressure conditioned response. The magnitude of the conditioned blood pressure changes in all dogs ranged from 4 to 26 mm Hg. Girden noted that, when the dogs were tested in the absence of the paralyzing drug, the conditioned response did not occur. He suggested that the blood pressure responses may not have occurred in the nonparalyzed state because of the presence of competing motor responses. It should be noted that an appropriate control condition for sensitization and pseudoconditioning was not included in the design of the study.

Stimulation of isolated peripheral nerves served as a US in two Russian experiments. In the first experiment, Kozenko (1952) stimulated the peripheral end of the sectioned cervical vagus in nine dogs. Hydrostatic stimulation of the intact carotid sinus served as the US in eight other dogs. In the case of both USs, the unconditioned blood pressure reaction was a decrease. The blood pressure orienting response to a bell CS was either a biphasic reaction, consisting of an increase followed by a decrease, or a monophasic increase. Conditioned decreases in blood pressure were observed using both types of US. However, conditioned responses reinforced by the carotid sinus US appeared after only 20 to 30 pairings, while 50 to 100 pairings were needed to obtain conditioned responses when the vagal stimulation US was used. In addition, the conditioned responses based on vagal stimulation were reported to be transitory, appearing on some trials but not on others.

In the second Russian study, classically conditioned changes in blood pressure were compared in dogs and cats (Kit, 1958). A tone

CS was paired with stimulation of the phrenic nerve as the US. In dogs the conditioned response was reported to be similar to the unconditioned response produced by the US. Furthermore, conditioned responses were present after 10 to 30 pairings, whereas 100 pairings failed to produce conditioned blood-pressure changes in cats. Additional details of the experiment were not translated in the publication.

Dykman and Gantt (1960) examined heart rate and blood pressure in two dogs receiving a foot-shock US and two tones of different frequencies in a CS+ vs CS- differential conditioning situation. Two other dogs were given conditioning training in prior sessions, and blood-pressure responses to three tones paired with three different shock intensities were studied in these animals. It was found that conditioned blood-pressure increases accompanied the previously established conditioned heart-rate changes in the two "experienced" dogs. In addition, the blood-pressure responses were parallel to conditioned heart-rate increases in that the magnitude of both conditioned responses was proportional to the intensity of the US. The magnitude of the systolic-pressure response of these two dogs to the CS+ and CS- after 36 trials was 16 and 3 mm Hg, respectively. It was reported that in the two "naive" dogs, blood-pressure differentiation between the two tones was evidenced by significantly larger increases to the CS+ than to the CS-. The magnitude of the systolic-pressure change in these two dogs to the CS+ and CS- after 165 trials were 11 and 3 mm Hg, respectively. In each pair of dogs,

conditioned cardiovascular responses occurred before conditioned leg-flexion reactions.

Mack, Davenport, and Dykman (1961) reported conditioning blood pressure, heart rate,and leg flexion in six dogs. They administered 250 conditioning trials followed by 200 extinction trials. A differential conditioning paradigm was used in which the CS+ was a tone paired with electric shock to the foreleg, and the CS- a different tone not paired with shock. They found that during extinction, differential blood-pressure responding was more reliable than heart-rate responding. There was also some indication that the same relationship between blood pressure and heart rate was present during conditioning. The magnitude of the systolic-pressure change of the six dogs to the CS+ was approximately 15 mm Hg, whereas the systolic-pressure change to the CS- was only 4 mm Hg. Little evidence of leg flexion conditioning was obtained.

A special conditioning procedure which generated a chronic state of hypertension in dogs was described by Napalkov (1963). First the dogs received a series of aversive stimuli (USs) including electric shock, light flashes,and loud noises. Initially, these stimuli produced elevations in blood pressure of 30 to 50 mm Hg. Upon repeated administrations however, the pressor responses vanished. The experimental procedure was then changed such that one of the USs (i.e. shock) was applied once at the beginning of the experimental session. This single presentation was followed by repeated presentations of a CS that had previously been paired with that US during

an earlier conditioning session. It was found that initial presentations of this CS elevated baseline blood pressure by 30 to 40 mm Hg and that these elevations increased in magnitude with successive CS-alone trials. In fact in one dog, blood pressure rose from 130 mm Hg (before training) to 250 mm Hg after exposure to this procedure. In addition, it was noted that this hypertensive state persisted for many months even though no additional trials were administered.

Dykman, Mack, and Ackerman (1965) studied heart rate, blood pressure, respiration and leg flexion in six dogs using a differential conditioning design. Two tones of different frequencies were used as CS+ and CS-. The US was an electric shock applied to the animal's foreleg. Nonspecific motor activity preceded autonomic responding to the CS+, but conditioned autonomic reactions usually occurred before conditioned leg flexion. Differentiation between the CS+ and CS- was evident for heart rate, leg flexion, blood pressure, and respiration, although heart-rate and leg-flexion differentiation was more consistent than that of blood pressure or respiration. The directions of the heart rate and blood-pressure conditioned changes were generally increases. Based on all six dogs, the difference between blood-pressure responding to CS+ and CS- was 8 mm Hg by the end of conditioning. However, on terminal conditioning trials, the conditioned heart-rate response was multiphasic consisting of an acceleration, followed by a deceleration, and then another acceleration. Correlation tests between the magnitudes of heart-rate and blood-pressure responses during the experimental

sessions ranged from -.50 to +.55 with none of the values being significant. Similar correlations between blood pressure and respiration were also carried out. In this case, the correlations were consistently positive and two of six were significant.

Newton and Perez-Cruet (1967) used two tones of different frequencies in a differential conditioning paradigm involving nine dogs. An electric shock to the foreleg served as a US. All dogs showed heart-rate accelerations to the CS+ and CS- on pretest trials given prior to conditioning. In addition, four of the dogs exhibited a brief, short-latency heart-rate deceleration to the CSs on these trials. During conditioning all dogs showed conditioned increases in heart rate with some of the animals also showing short-latency decreases. In general, blood-pressure changes during conditioning matched those found for heart rate. That is, when heart rate increased, blood pressure increased, and when heart rate decreased, blood pressure decreased. The magnitudes of the blood-pressure conditioned responses of the dogs ranged from 7 to 25 mm Hg. However, in two dogs heart rate and blood pressure went in opposite directions during the latter part of the CS. Consistent unconditioned heart-rate accelerations to shock were found, but unconditioned blood-pressure reactions were sometimes increases and sometimes decreases. A single dog was paralyzed with d-tubocurarine and succinyl choline following conditioning. This procedure had the effect of reducing the magnitude of conditioned heart rate, but not conditioned blood-pressure responses. The authors suggested that this differential

effect may have been due to the influences of the paralyzing agent on the cardiac nerves controlling heart rate. No specific statistical comparisons were made between heart rate and blood pressure.

Blood pressure, heart rate, respiration, and hindleg movement were measured by Antal (1968) in a classical conditioning study involving 17 dogs. The US was skeletal-motor movement on a treadmill, and the CS was the sound of the treadmill in operation. After habituation of orienting responses, only two or three paired trials were required to produce conditioned increases in heart rate, blood pressure and respiration. These conditioned reactions were similar in direction and magnitude to the unconditioned changes. The magnitude of the conditioned blood-pressure reaction, averaged across all dogs and all trials, was approximately 15 mm Hg. The author suggested that the pattern of autonomic responses that occurred to the CS represented adaptive changes to anticipated muscular activity. However, it can be noted that on extinction trials, the heart rate and blood pressure were seemingly not strictly related to each other. That is, blood-pressure changes extinguished before heart-rate changes. Respiratory changes were last to extinguish. No control for sensitization or pseudoconditioning was included in the investigation.

Katcher, Soloman, Turner, LoLordo, Overmier, and Rescorla (1969) curarized six normal and six cardiac-sympathectomized dogs in a differential conditioning study and recorded both heart rate and blood pressure. Two tones of different frequencies served as a CS+

and CS-; the US was an electric shock. It was suggested that the appearance of diminished or absent heart-rate responses to shock in sympathectomized dogs indicated that unconditioned heart-rate accelerations were in part due to increased sympathetic activity. On the other hand, unconditioned pressor reactions of the sympathectomized dogs were similar in magnitude to those of unoperated dogs. Differentiation of heart-rate, systolic and diastolic blood-pressure responses to the CS+ and CS- occurred, but the most reliable differentiation was revealed by diastolic blood-pressure reactions. It was noted that during the CS+, conditioned heart-rate increases occurred prior to conditioned blood-pressure increases. For all dogs, systolic blood-pressure reactions to the CS+ ranged from 5 to 37 mm Hg, and diastolic pressures ranged from 5 to 38 mm Hg. The directions of unconditioned heart-rate and blood-pressure changes were also increases, but blood pressure remained elevated following the US several seconds after heart rate began to decrease. This cardiodeceleration was thought to arise from baroreceptor-induced increases in vagal activity.

Andrus, Gantt, Plumlee, and Gross (1970) reported an unsuccessful attempt to condition cardiovascular responses in 16 dogs using a tone CS and stimulation of the proximal end of the sectioned vagosympathetic trunk as a US. Although vigorous unconditioned heart-rate and blood-pressure changes were elicited by the US, no conditioned changes in either blood pressure or heart rate were seen even though some dogs received several hundred conditioning trials. It

will be recalled that Kozenko (1952) did find conditioned changes in blood pressure using stimulation of the peripheral end of the sectioned vagus as the US.

Antal and Gantt (1970) used hindleg shock to reinforce conditioned blood flow, blood pressure, respiratory, and heart rate responses to a whistle CS in seven dogs. The direction of the conditioned heart rate and blood-flow reactions was an increase, while that of the blood-pressure response was a decrease. Similarly, heart rate and blood flow increased to shock and blood pressure decreased. Conditioned heart rate, blood flow, and blood pressure responses were abrupt and nearly simultaneous with the start of hindleg flexion, and blood pressure and blood flow conditioned responses outlasted leg flexion. The overall magnitude of the conditioned blood-pressure change averaged 11 mm Hg. During extinction, the responses became more distinguishable with flexion extinguishing first, followed by blood pressure, blood flow, and heart rate in that order. The authors concluded that blood pressure, heart rate, and blood flow were conditioned together and were not separable. In their view, different components of the cardiovascular system interacted among themselves to produce an integrated effect within that system. However, it should be pointed out that no specific tests comparing heart rate and blood pressure were carried out in this study.

Monitoring heart-rate and blood-pressure changes of five dogs, Kakigi (1971) tested for the presence of generalization and differentiation with five tones. Conditioned cardioaccelerations were noted

with peak magnitudes occurring in response to the tone paired with electric shock to the foreleg. Increases in blood pressure occurred in response to the tones but no reliable differential responding to the tones was noted. In one dog, the magnitude of the diastolic-pressure response to the CS ranged from a low of 8 to a high of 14 mm Hg. Correlation analyses between heart rate and blood pressure were performed. Correlations between systolic pressure and heart rate were only +.14 during the baseline period and +.39 during the CS, while correlations between diastolic pressure and heart rate were much higher, being +.72 during the baseline period and +.63 during the CS. However, more detailed analyses indicated that this apparent relationship between diastolic pressure and heart rate was present during the early part but not during the terminal part of the CS. On the assumption that responding during the later portions of the CS reflects conditioning, Kakigi concluded that conditioned blood pressure and heart rate seemed to be independent.

Bergamaschi and Longoni (1973) studied cardiovascular changes of three dogs to a tone CS and a loud-sound US that was produced by discharging a pistol. For both heart rate and blood pressure, the directions of the conditioned responses matched those of the unconditioned responses; in each case, the directions of the responses were increases. The magnitude of the conditioned blood-pressure change in the dogs averaged across all trials was 13 mm Hg. The blood-pressure and heart-rate conditioned and unconditioned responses were attenuated by blocking normal sympathetic activity with pro-

pranolol after conditioning was completed. The administration of temazepam, a tranquilizing drug purported to act on the limbic system, produced similar effects. The authors concluded that conditioned changes in both heart rate and blood pressure conceivably resulted from increased sympathetic tone and that these changes may be initiated by components of the limbic system. It should be noted that conditioning was defined on the basis of statistically significant differences between baseline activity and activity in the presence of the CS. No sensitization or pseudoconditioning control group was included in the design of the experiment.

In summary, the above studies showed that the directions of conditioned and unconditioned heart-rate responses of dogs were the same with both reactions generally being cardioaccelerations. The same general relationship was found for blood pressure in that conditioned and unconditioned responses were generally increases in blood pressure. In one study in which the blood-pressure unconditioned response was a decrease, the conditioned response was also a decrease. It may also be noted that, except for one investigation, conditioned increases in heart rate and blood pressure occurred together, yet there was little evidence that the two responses were systematically related to each other. In addition, unconditioned increases in heart rate and blood pressure appeared to occur together with little evidence being found that they were dependent upon each other.

It should also be noted that, with respect to most of the

studies employing humans and primates, larger-magnitude conditioned blood-pressure responses were seen in dogs. For example, the mean systolic pressure changes of humans and primates ranged from 2 to 9 mm Hg, while the mean changes of dogs ranged from 8 to 13 mm Hg. Although differences in magnitudes of the responses between the various experiments could have been due in part to differences in measurement procedures, other factors are probably also involved.

Rabbits. A series of experiments involving classical conditioning of heart rate and blood pressure in rabbits has been reported by Schneiderman and his associates. The series began with a study by Yehle, Dauth, and Schneiderman (1967), who studies cardiovascular responses of 32 rabbits using a tone CS and a 20-ma electric shock just lateral to the orbit of the eye as a US. One-half of the animals were immobilized with gallamine, and the remainder were untreated. For both groups conditioned heart rate and blood-pressure changes occurred and were opposite in direction. Conditioned heart rate was a decrease, while conditioned blood pressure was an increase of 12 mm Hg at the beginning of conditioning, declining to 6 mm Hg by the end of conditioning. The latency of the conditioned blood-pressure responses was 1.94 sec and did not change across trials. The heart-rate reaction shortly after shock termination was decelerative, while the unconditioned blood-pressure response was biphasic (pressor-depressor). The authors concluded that conditioned heart-rate decelerations in rabbits may be compensatory responses to a sympathetically-induced elevation in blood pressure elicited by the CS. However, because

there were occasions in which conditioned heart-rate changes occurred without accompanying changes in blood pressure, the authors also felt that the two responses were not necessarily tied together.

In a classical conditioning study with a total of 66 rabbits, Schneiderman, VanDercar, Yehle, Manning, Golden and Schneiderman (1969) recorded both blood pressure and heart rate. They employed a two tone CS+ vs CS- differential conditioning paradigm, but unlike the previous experiment, a less intense, 3-ma shock to the eyelid was used as a US. Pearson product-moment correlations between unconditioned blood-pressure increases and unconditioned heart-rate decreases ranged from -.45 to -.66, supporting the contention that unconditioned cardiodecelerations were related to unconditioned pressor responses. However, dihydro-ergotoxine mesylate, an alpha-adrenergic blocking agent, attenuated the unconditioned decreases in heart rate. It was suggested that this result indicated that mechanisms in addition to baroreceptors were likely involved in mediating unconditioned heart-rate reactions. Moreover, even though no conditioned changes in blood pressure were observed, heart-rate conditioning was present. Taken altogether, these outcomes suggested that unconditioned heart-rate and blood-pressure reactions were at least partially related to each other, but that conditioned heart-rate decreases did not appear to depend on blood-pressure reactions. In addition, it should be noted that no blood-pressure conditioning occurred in this study using a 3-ma

shock US, whereas it did occur in the previous report using a 20-ma shock. This suggests that blood-pressure conditioning may be more difficult to obtain than heart-rate conditioning.

The following experiments were somewhat different from the studies with rabbits discussed above in that intracranial stimulation, rather than peripheral shock, was used as a US. VanDercar, Elster, and Schneiderman (1970) used electrical stimulation of one lateral geniculate as a CS+ and stimulation of the contralateral geniculate as a CS- in 14 curarized rats. Septal or hypothalamic stimulation was used as a US. Heart-rate conditioned responses were more reliable than blood pressure reactions. Blood-pressure conditioned responses, defined as pressure deviations from baseline in excess of 2 mm Hg, occurred in less than 11% of the acquisition trials. When present, the response had a latency of approximately 1.5 sec. The directions of conditioned and unconditioned heart-rate responses were decreases, while those of conditioned and unconditioned blood-pressure changes were increases. It was found that the latencies of unconditioned blood-pressure responses were shorter than those of unconditioned heart-rate reactions. Furthermore, the fact that conditioned heart-rate decreases often occurred in the absence of conditioned blood-pressure increases indicated to the authors that mechanisms other than those involving blood pressure contributed to cardiodecelerations.

Powell, Goldberg, Dauth, Schneiderman, and Schneiderman (1972) reported an investigation of unconditioned blood pressure and heart-rate responses in separate groups of rabbits receiving either

phentolamine, propranolol, atropine methylnitrate, or atropine sulfate. Data from 42 stimulation sites in the septal region and hypothalamus illustrated that high-frequency, short pulse-train stimulation produced unconditioned pressor responses accompanied by unconditioned cardiodecelerations. Phentolamine, which blocks vasoconstriction, reduced the magnitude of the blood-pressure increases and heart-rate decreases, suggesting that the unconditioned cardiodecelerations were secondary to increased baroreceptor activity. Propranolol, which blocks sympathetically-induced elevations in heart-rate, increased the magnitude of cardiodecelerations but seemed to have little influence on blood-pressure reactions. Atropine sulfate and atropine methylnitrate both abolished heart-rate decelerations without appreciably changing blood-pressure responses. It was concluded that unconditioned heart-rate decelerations in rabbits were probably mainly reflexive responses to sympathetically-induced blood-pressure elevations.

Metcalf and Schneiderman (1973) noted the effects of six-hydroxydopamine (6-OHDA) on heart rate and blood pressure in 36 rabbits. They used stimulation of one lateral geniculate as the CS+, and stimulation of the other geniculate as the CS- in a differential conditioning paradigm. The US was stimulation of the septal region or hypothalamus. Before conditioning five groups of six rabbits each were injected interperitoneally with different dosages of 6-OHDA. It will be recalled that this drug reduces sympathetic tonus of the arterioles by destroying peripheral post-ganglionic

terminals. Another group of six rabbits was injected with saline. Six-hydroxydopamine abolished both unconditioned blood-pressure increases and unconditioned heart-rate decreases. Conditioned blood-pressure increases were also blocked, but conditioned heart-rate decreases were not influenced by the drug. Hence, it was concluded that, contrary to unconditioned heart-rate decreases, conditioned heart-rate decreases may not depend upon blood-pressure changes. The authors suggested that a central command for vasoconstriction may contribute to conditioned cardiodeceleration even though execution of this response was prevented peripherally by 6-OHDA.

In a further study of the effects of pharmacological agents on conditioned and unconditioned cardiovascular responses, Sampson, Francis, and Schneiderman (1974) measured heart rate, blood pressure and lever lifting in six hares. They used a US consisting of electrical stimulation of the septal area or hypothalamus, and a two tone CS+ vs CS- differential conditioning procedure. This procedure was superimposed on lever-lift responding forming a CER paradigm. Suppression of lever-lifting was thought to aid in the assessment of central vs peripheral effects of the drugs. Propranolol did not appreciably influence heart rate, either conditioned or unconditioned, but did lower baseline heart rate. Propranolol also failed to affect lever lifting. It was suggested on the basis of this finding, that sympathetic activity may not contribute substantially to the development of conditioned cardiodecelerations in rabbits. On the other hand, atropine sulfate attenuated both conditioned and unconditioned

heart-rate decreases as well as lever lifting. Consequently, the effects of methylatropine were tested since it passes the blood-brain barrier less readily than atropine sulphate. Methylatropine, at all but the highest dose, did not influence lever-lifting but it did abolish heart-rate conditioned responses. After combining the atropine and propranolol data, the authors concluded that heart-rate decelerations were vagally mediated and not due to inhibition of sympathetic activity. Phentolamine abolished unconditioned blood pressure increases and unconditioned heart-rate decreases, but it did not eliminate conditioned heart-rate decelerations. No blood pressure conditioned responses were observed. These results led the authors to suggest that the unconditioned cardiodecelerations were reflexive responses to sympathetically-induced unconditioned pressor responses, while conditioned cardiodecelerations were not strictly related to blood-pressure changes.

Heart rate and blood-pressure responses were measured in 38 rabbits while they were receiving classical eyeblink conditioning for 20 days (Powell and Kazis, 1976). A two tone, CS+ vs CS- differential conditioning procedure was used, and a 5-ma electric shock to the eyelid served as a US. The CS-US interval was 1 sec. Conditioned decrease in both heart rate and blood pressure developed to the CS+ early in training. The mean depressor changes of all subjects was 2.5 mm Hg at this point in the experiment. However, with further training, many animals displayed a change in the direction of both responses. Conditioned heart rate and blood pressure both changed to increases with the average pressor change for all subjects being

1.5 mm Hg on the last day of acquisition. Correlation analyses indicated that the magnitudes of conditioned blood-pressure changes were positively correlated with those of conditioned heart-rate changes. That is, depressor responses were reliably correlated with heart-rate decelerations, and pressor responses were correlated with heart-rate accelerations. Unconditioned heart-rate and blood-pressure reactions were not reported. When an interstimulus interval of 4 sec was employed, only conditioned decreases in heart rate and blood pressure were evident. The data from this part of the study were not subjected to correlation tests. The authors suggested that the early decreases in heart rate and blood pressure with the 1 sec CS-US interval may have been part of a defensive response. It is not clear why the direction of the blood-pressure conditioned response was initially a decrease in this study as opposed to the consistent increase observed in earlier experiments with rabbits. Also, in those early investigations, a consistent decrease in heart rate was found during conditioning.

In general, the above studies appeared to show that conditioned heart-rate responses in rabbits were independent of changes in blood pressure, but that unconditioned heart-rate responses may not be. Moreover, in almost all cases, the directions of the conditioned heart-rate and blood-pressure responses were the same as those of the unconditioned reactions.

Cats. Hein (1969) classically conditioned 20 cats using electric shock to the foreleg as a US and a two tone CS+ vs CS- training

design. Heart rate, blood pressure, respiration, EEG, electromyographic (EMG) activity, and galvanic skin potential (GSP) were recorded. The heart-rate component of the orienting response to the CS was minimal or non-existant. Only five of the 20 cats displayed a consistent response, and that was an acceleration. The nature of the blood-pressure orienting response was not discussed. Conditioned decreases in heart rate and blood pressure occurred while the unconditioned reactions were both increases. On the basis of a polygraphic record of one cat, the blood-pressure conditioned response occurred early in the CS, and the magnitude of the response was approximately 15 mm Hg. In addition, apnea and a decrease in EMG activity were present during the CS+. Succinyl choline-induced muscle paralysis failed to influence conditioned heart-rate decreases, while Flaxedil paralysis and atropine, a parasympathetic antagonist, abolished the response. The effect of atropine on blood pressure was not reported. From the observed influence of atropine, it was concluded the conditioned heart-rate responses in cats were primarily vagally mediated. Although specific tests of the relationship between heart rate and blood pressure were not carried out, Hein suggested that decreases in heart rate and blood pressure may have been part of an anticipatory adjustment to pressor responses elicited by the US. Furthermore, it should be noted that no statistical evidence was provided to support the reliability of any of the findings in the experiment.

Rats. The only report of classical conditioning of blood

pressure in rats that could be found was that of Pappas, DiCara, and Miller (1972). They examined blood pressure and heart rate in 38 rats paralyzed with d-tubocurarine. The CS was a compound stimulus of tone plus light, and the US an electric shock applied to the hind paws. The CS-US interval was 8 sec. One half of the animals were sympathectomized with interperitoneal injections of 6-OHDA, and the other half received no drug. The non-drugged animals showed a conditioned increase in blood pressure having two peaks. The first peak occurred 2 sec after CS onset and the second peak 5 sec later. On test Trial 7, for 10 nondrugged rats, the magnitudes of both the first and second peaks were approximately 7 mm Hg above baseline. The unpaired-control groups failed to display significant blood-pressure changes during the CS, and on this basis, it was concluded that blood-pressure conditioning occurred. No direct statistical comparisons of experimental and control groups were made. Sympathectomy appeared to eliminate the conditioned blood-pressure reaction with both the conditioning and unpaired-control groups displaying equivalent long-latency increases in blood pressure to the CS. The blood-pressure unconditioned response to shock was a monophasic increase in the sympathectomized and non-drugged groups. The magnitude of this response was reduced in the sympathectomized group. No evidence of conditioned heart-rate reactions was found in any of the groups. However, shock did produce an unconditioned increase in heart rate, the magnitude of which was reduced by sympathectomy.

Unavoidable foot shocks were delivered to 32 rats divided into

two groups by Williams, Eichelman, and Ng (1972). Half of the rats in each group were shocked in pairs, and the others were shocked alone. One group of 16 animals received intracisternal injections of 6-OHDA prior to the administration of footshock and the other group of 16 received an injection of the vehicle. The degree of restraint imposed upon the animals was not mentioned, but it may be assumed that the paired rats were unrestrained since shock-induced fighting occurred in these animals. Six-hydroxydopamine reversed the direction of the unconditioned blood-pressure response of the paired rats such that a significant increase in pressure occurred in the 6-OHDA-treated rats whereas a significant decrease in pressure occurred in the vehicle-treated rats. In addition, 6-OHDA increased the magnitude of the pressor response in the isolated rats relative to that of the vehicle-treated group. The authors claimed that the effect of 6-OHDA was restricted to the brain and that peripheral sympathetic terminals were not destroyed. On this basis, they contended that central catecholaminergic mechanisms were involved in the mediation of blood-pressure responses to shock.

A two tone CS+ vs CS- differential conditioning design was employed by Howard, Smith, Mueller, and Breese (1974) to investigate heart rate and motor responses of 32 rats. It was not clear from the description of the study whether the rats were restrained or unrestrained. Those animals injected intracisternally with 6-OHDA displayed significantly lower basal heart-rate and blood-pressure levels than those of untreated control animals. It was found that

conditioned cardiodecelerations were present in the untreated group to which a footshock US was administered. A second untreated group showed conditioned cardioaccelerations when a tailshock served as the US. Similarly, motor activity also reportedly decreased to the CS reinforced by footshock and increased to the CS reinforced by tailshock, although these data were not subjected to statistical analysis. Neither footshock nor tailshock produced conditioned heart-rate reactions in the drug-treated groups. Interestingly, 6-OHDA did appear to enhance unconditioned increases in heart rate to both tailshock and footshock. The 6-OHDA-treated and non-drugged control rats were also give desoxycorticosterone (DOCA) plus NaCl and were uninephrectomized. It was found that this combination of factors produced significant hypertension (i.e. 184 mm Hg) in control animals. An unspecified lower level of hypertension was also found in 6-OHDA-treated animals. The authors suggested that 6-OHDA may have led to less hypertension because the drug destroyed central catecholamine-containing neurons which presumably play a role in the development of hypertension. In addition, the authors noted that the 6-OHDA animals drank less saline than non-treated animals, and this reduction in saline consumption could have contributed to a less profound state of hypertension. Failure to find conditioning in the 6-OHDA-treated animals was attributed to selective destruction of central catecholamine receptors. On this basis, the authors suggested that 6-OHDA decreased the ability of rats to acquire new responses. It was also suggested that the

exaggerated unconditioned heart-rate responses could have resulted from potentiated somatic reactions to shock.

In summary, the results of all of the above investigations indicate that the relationships between changes in heart rate and blood pressure that may be present during classical aversive conditioning are exceedingly complex. In some species such as humans, rabbits, and perhaps rats, the direction of conditioned heart-rate changes (i.e. decreases in heart rate) were generally found to be opposite to that of conditioned blood-pressure reactions (i.e. increases in blood pressure). In spite of these findings, there was little evidence to support the notion that the blood pressure elevation mediated or controlled cardiodecelerations through, for example, the baroreceptor mechanism. For other species such as dogs, monkeys, ewes and cats, heart-rate and blood-pressure conditioned reactions appeared to change in the same direction, with both being either decreases or increases in activity. At the same time, however, some of the results pointed to the possibility that at least in humans and dogs, the direction of conditioned blood-pressure responses may vary and follow the direction of the unconditioned blood-pressure reactions, as would be predicted on the basis of the Pavlovian stimulus-substitution theory of classical conditioning. Evidence bearing on this last point was obtained by comparing the results of separate unrelated studies. No single investigation was located in which an effort was made to vary the direction or topography of the conditioned blood-pressure response by varying the

unconditioned response. For a review of heart rate and blood pressure data from the above investigations. see Appendix A. Here each study is summarized with respect to the type of CS and US employed and with respect to the directions of conditioned and unconditioned cardiovascular responses.

The present experiment had two objectives. The first was to provide detailed information on the relationship between heart rate and blood pressure activity in rats receiving classical aversive conditioning. A second, related objective was to determine whether the type of US employed influenced the development, direction, or topography of heart rate and blood pressure conditioned responses. To accomplish this objective, a comparison was made of the effects of electric shock as one US and the inhalation of ammonia fumes as the other US. Although little is known about the nature of the rat's blood pressure reactions to these two types of stimulation, it has been established that shock produces primarily cardioaccelerations, whereas breathing ammonia fumes produces profound cardiodecelerations (Fitzgerald and Hoffman, 1976). It was anticipated on the basis of these findings that the two stimuli would also elicit quite different unconditioned blood pressure reactions.

METHODS

Subjects

The subjects were 48 hooded Long-Evans female rats purchased from Simonsen Laboratories and maintained on a 12-hr light-dark schedule by the Department of Animal Care at the University of Oregon Health Sciences Center. The rats ranged in weight from 250 to 275 gm and were given food and water freely prior to conditioning.

Apparatus

The animals were restrained in a plastic, inverted-U-shaped small-animal holder purchased from E & M Instrument Co. Guillotine-type plastic inserts in the holder were adjusted to fit snugly in front of and directly behind the animal. The holder was placed in a 40.6-cm long x 11.4-cm wide x 12.2-cm high stainless-steel enclosure equipped with two .80-cm inside-diameter teflon ports situated directly in front of the rat and a 2.5-cm exhaust opening located behind the rat. To mask unwanted auditory signals from reaching the animal, the stainless-steel enclosure was located in a small-animal, Industrial Acoustics Corporation, sound-isolation chamber equipped with a 7.5-cm ventilation fan and a 8.3-cm speaker mounted on one wall of the chamber. Additional masking of extraneous auditory signals was accomplished by presenting white noise measuring about 75 db (sound pressure level re .0002 dyne/cm^2) through the speaker.

The electrocardiogram (ECG) was recorded on a Grass Model 5 Polygraph from two 20-gauge hypodermic needles inserted subcutaneously on

either side of the thoracic cavity of the rat. An automated recording system, described in detail by Fitzgerald, Vardaris, and Teyler (1968), provided a record of the heart beats occurring within each trial. The system contained a low-force-lever type Microswitch which was mounted directly above the ECG polygraph pen so that the R wave of the QRS complex of each cardiac cycle activated the switch. Each triggering of the Microswitch was coded in a transistorized counting network of AND gates, OR gates, and associated memory devices. At the end of selected time periods, the accumulated heart-beat totals were punched on tape using a Tally paper-tape perforator. The accuracy of the recording system was periodically checked with an oscillator by substituting a 10-Hz signal for the incoming ECG signal.

An additional channel of the polygraph was used to record arterial blood pressure from the middle caudal artery of the rat's tail. One end of a 5-cm section of 0.2-cm outside diameter polyethylene tubing was inserted into the artery, and the other end was attached to a 21-ga Butterfly infusion cannula. The cannula consisted of a 29-cm section of 1.2-mm polyethylene tubing with a 5-mm plastic fitting attached to the end of the tubing. The fitting was connected to a Statham P23-Db pressure transducer mounted at the same level as the artery. The output of the transducer was fed into the bridge circuit of a Grass 5P1 preamplifier whose sensitivity was set to 2 mv/cm for all animals. This sensitivity setting meant that a change in pressure of 10 mm Hg produced a pen deflection of 1 cm.

The CS was a 6.5-sec, 2.9-kHz, 85-db tone produced by a 2.2-cm

Mallory Sonalert device mounted in the ceiling of the stainless-steel enclosure. The shock US was a 0.5-sec, 1.3-ma, 60-cycle a.c. electric shock delivered by a Grason Stadler shock generator (E6070B) through the ECG electrodes. A relay was used to switch the animal's ECG signal out of the recording circuit when the shock was delivered. The intensity of the shock was monitored by measuring the voltage drop across a fixed 100-ohm resistor in series with the shock electrodes. The ammonia US was delivered by an olfactometer similar to one described by Tucker (1963) and employed in a previous study (Fitzgerald and Hoffman, 1976). It consisted of a network of teflon and glass tubing, precision regulator valves, glass flasks to house volatile fluids, and calibrated air-flow meters. A continuous flow (32 L/min) of source air was passed through a charcoal filter and then dried in a Van-Air dryer before entering the rat's chamber. An electrically operated solenoid manufactured by Flurocarbon Company operated for 1 sec allowing approximately 142 ml of an ammonia-air mixture from a 58% NH_4OH solution to blend with the background air flow. The mixed air passed into the stainless-steel enclosure housing the animals and was withdrawn through the exhaust port in approximately 2.5 sec. There was no perceptible change in air flow or air pressure associated with the operation of the solenoid, and the small click of the solenoid was masked by the combination of rushing background air and white noise.

Two rats were conditioned concurrently in two identically equipped chambers with trials alternating between rats. Trials were initiated

by a film-tape programmer with specific events within a trial programmed and timed by Massey Dickinson logic modules. The repeat accuracy of the modules was .05%.

Procedure

Prior to the beginning of the conditioning session, the cannula for recording blood pressure was surgically implanted under general anesthesia. Anesthesia was induced by a 1% concentration of Halothane controlled by an Ohio-Medical Side-Arm Vaporizer and delivered through a small plastic funnel placed over the rat's nose. A ventromedial incision was made in the rat's tail, and the middle caudal artery was freed from connective tissue. The relative position of this artery in the rat's tail is shown in Figure 1. The artery was clamped proximally and a tight suture (000 silk) was tied 4 to 5 mm distal to the clamp. The arterial wall was incised and then dilated by direct application of 2% xylocaine. A slightly beveled section of a Butterfly cannula was pushed rostrally into the artery at least 1.5 cm or to a point where resistance prohibited further movement of the cannula. Two sections of suture were tied around the artery to secure the cannula. One of the sutures was positioned proximally near the termination of the cannula, and the other was placed caudally near the point on the artery where the cannula was inserted. To provide a rigid support for the cannula, Dow Corning Medical Silastic Cement was liberally applied along the entire length of exposed artery and several sutures were made around the tail. The exposed end of the tubing was sealed after introduction of approximately .1 ml of 5% sodium heparin. The animal was then placed in the plastic restrainer, and the animal's tail was secured to the base of the restrainer with adhesive tape. All rats were allowed at least 90 min to recover from the anesthesia before

Figure 1. A diagram of the major arteries in the rat's tail indicating the position of the middle caudal artery.

Figure 1

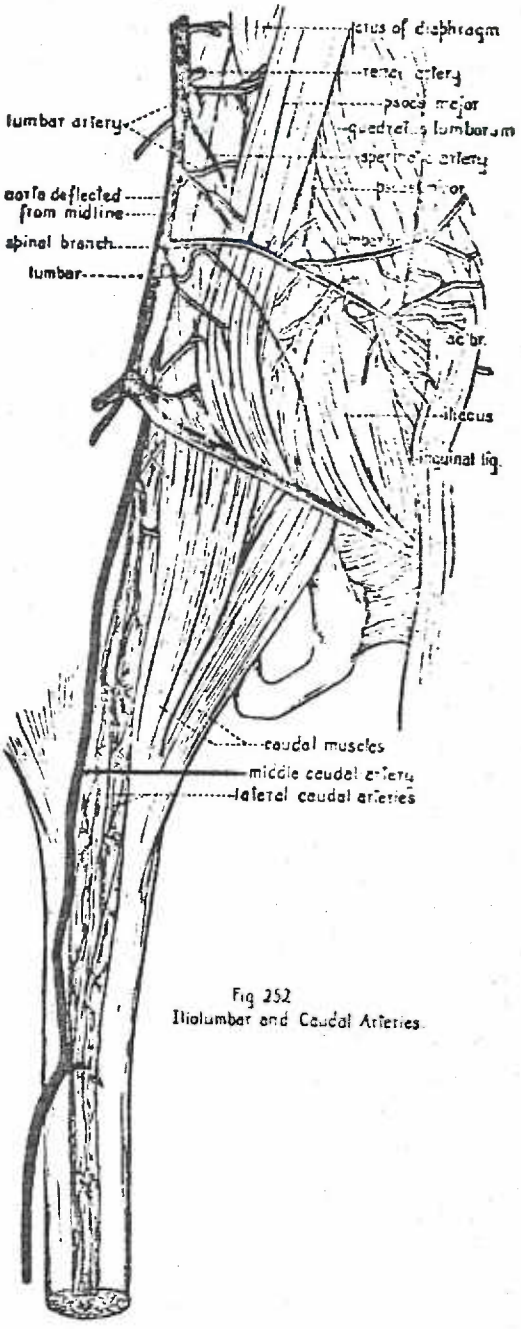


Fig 252
Iliolumbar and Caudal Arteries

conditioning was initiated.

To prevent blood from clotting in the transducer and cannula, a .5 ml/hr flow of 5% heparin solution (50 units/ml) was presented through the cannula during the conditioning session by means of a Harvard variable speed micro-infusion pump. At this flow rate, approximately 2 ml of the heparin solution was infused into the animal during the 4-hr conditioning session. Preliminary tests indicated that the action of the pump did not perceptibly alter the blood-pressure readings at the 2 mv/cm setting on the preamplifier that was used in the experiment.

Each rat was randomly assigned to one cell of a 2 x 2 factorial design providing four groups of 12 animals each. One dimension of the design was the type of US employed (electric shock vs ammonia fumes). The second dimension was whether the animal received a paired CS-US conditioning procedure or a pseudo-conditioning control paradigm consisting of explicitly-unpaired CS-US presentations. All animals received 10 pretest trials of the CS alone followed by 30 acquisition trials. Animals in the two conditioning groups received a delayed-conditioning paradigm with a CS-US interval of 6.0 sec. The .5-sec shock US occurred during the last .5 sec of the CS. The delivery of the ammonia-fumes US was also arranged such that the highest concentration of ammonia occurred during the last .5 sec of the CS. The animals in the two control groups were given explicitly-unpaired trials with the US following the CS by 70, 90, or 110 sec ($\overline{X}$ = 90 sec). The intertrial intervals for the CS-alone trials were 70, 90, or 110

($\overline{X}$ = 90 sec), and for the acquisition trials 180, 200, or 220 sec ($\overline{X}$ = 200 sec).

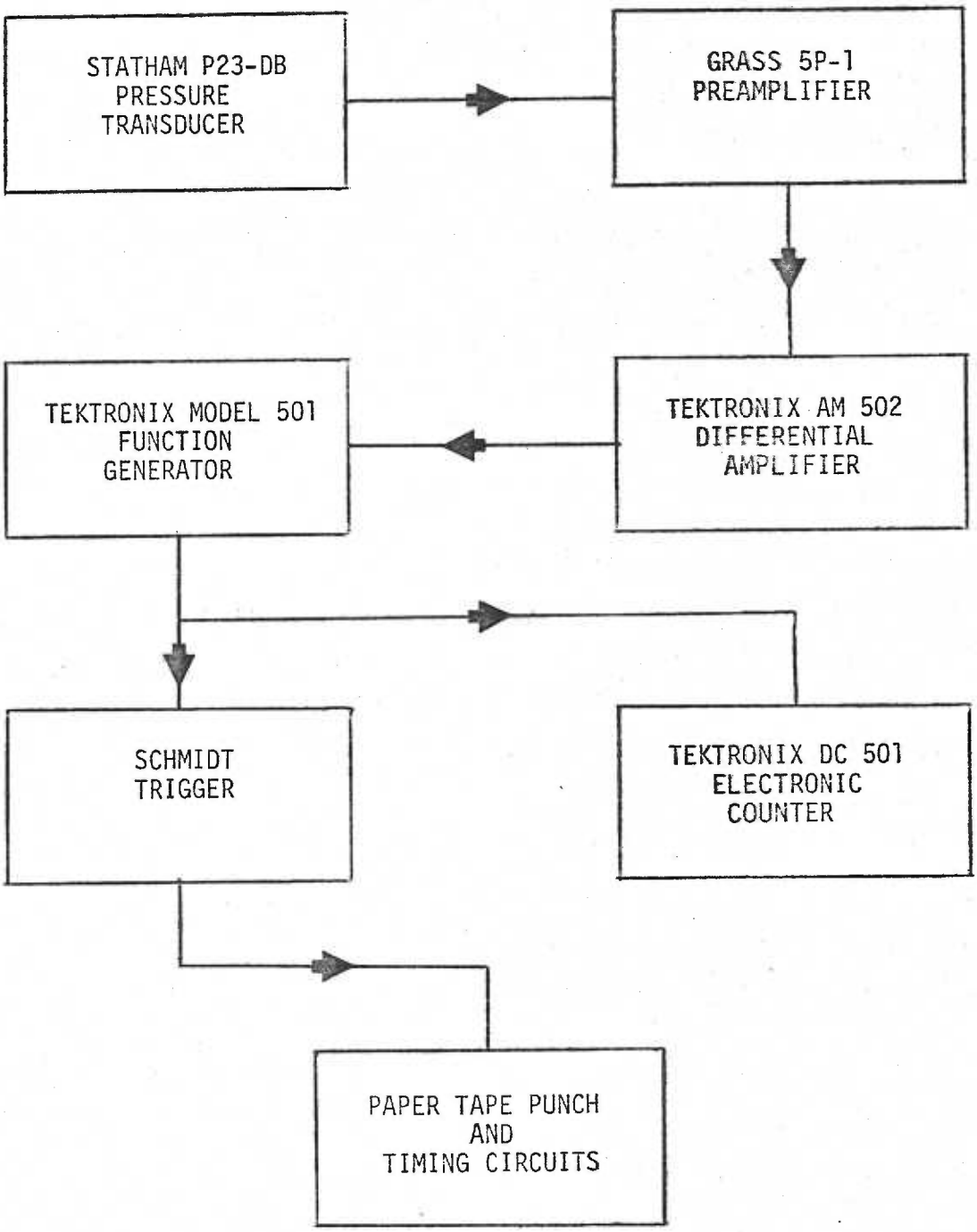
Heart rate and blood pressure were recorded in 13 successive counting periods with each trial. The duration of the first period was 6 sec and that of each subsequent period, 2 sec. The 6-sec period occurred immediately prior to the onset of the CS and provided a measure of baseline heart rate and blood pressure. The first three 2-sec periods composed the CS-US interval, and the remaining 2-sec periods constituted the post-US interval. Heart rate in beats-per-minute during the 6-sec baseline period was subtracted from the beats-per-minute rates during the succeeding 2-sec period to generate heart-rate difference scores for each trial. Similarly, for blood pressure the pressure in mm Hg during the 6-sec baseline interval was subtracted from the mm Hg pressure in each subsequent 2-sec period.

Blood-pressure recording system.

An on-line system which converted analog voltage changes to digital signals was developed to provide a quantitative record of blood pressure. A flow chart of the components in the system is shown in Figure 2. Basically, the system operated in the following manner. Blood-pressure changes detected by the Statham P23-Db pressure transducer were applied to the bridge circuit of a Grass 5P1 preamplifier. The output voltage of the preamplifier was fed into a Tektronix AM 502 differential amplifier which amplified the voltage by a factor of 5 and passed frequencies ranging from DC to 3 kHz. The output of the amplifier was applied to a Tektronix Model 501 function

Figure 2. A flow chart indicating the components of the blood-pressure recording system.

Figure 2


STATHAM P23-DB
PRESSURE
TRANSDUCER
GRASS 5P-1
PREAMPLIFIER
TEKTRONIX MODEL 501
FUNCTION
GENERATOR
TEKTRONIX AM 502
DIFFERENTIAL
AMPLIFIER
SCHMIDT
TRIGGER
TEKTRONIX DC 501
ELECTRONIC
COUNTER
PAPER TAPE PUNCH
AND
TIMING CIRCUITS

generator which served to convert the voltage to a frequency. In the absence of any input, the Tektonix unit was set to generate a continuous output frequency of 200 pulses/sec. The output frequency increased proportionately with positive input voltages and decreased proportionately with negative voltages. The output of the voltage-to-frequency converter was applied simultaneously to both a Schmidt trigger and a Tektronix DC 501 electronic counter for digital display. A transistorized counting circuit stored the pulses from the trigger, and at the end of a selected counting period, the total count was punched on paper tape.

The blood-pressure recording system was developed on the basis of extensive tests carried out before the beginning of the experiment. These tests showed that the mean arterial blood pressure of unanesthetized, restrained rats was approximately 110 mm Hg. Preliminary tests also showed that peak unconditioned blood pressure responses to shock and ammonia fumes were often on the order of 40 mm Hg above or below this average baseline. To record these responses, as well as smaller changes in blood pressure that occurred to the CS during conditioning, the bridge circuit of the Grass preamplifier was balanced with a standard pressure of 100 mm Hg in the system. This balancing procedure was carried out with the baseline position of the recording pen being slightly below the center of the ploygraph paper. In most cases, this arrangement meant that when a rat was connected to the transducer, the recording pen would return to approximately the center of the paper. However, because of individual differences in mean arterial pressures, it was sometimes necessary to adjust the balance voltage on the preamplifier to center the pen prior to the beginning of a conditioning session. Similar

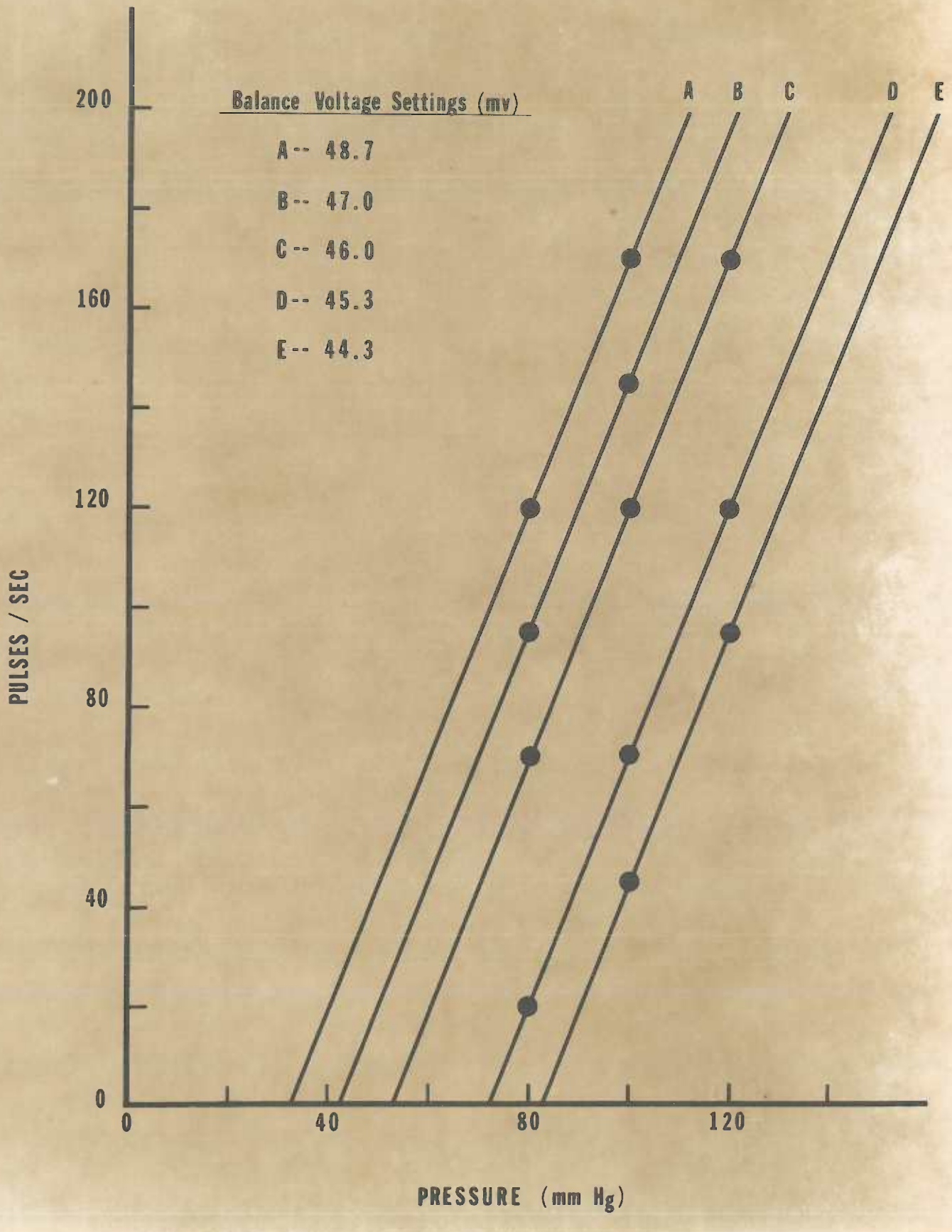
adjustments were occasionally required within a session. In each instance, the new balance-voltage settings were recorded for future use in calibrating the recording system for that animal.

Pilot work revealed that the relationship between the output of the Tektronix voltage-to-frequency converter, and the pressure applied to the Statham pressure transducer varied as a function of the balance voltage applied to the bridge circuit in the Grass amplifier. Therefore, to correctly transform the blood-pressure scores to mm Hg, it was necessary to calibrate the recording sytem for each balance voltage setting that was used for a given rat. The calibration procedure consisted of substituting a hand-pump mercury manometer for the rat at the end of the conditioning session and applying a series of pressures (80, 100, and 120 mm Hg) to the recording system at each balance voltage used for that rat. The numbers produced by the voltage-to-frequency converter were recorded for each pressure applied.

Examples of the relationship between pulses/sec (i.e. the output of the voltage-to-frequency converter) and mm Hg for different balance-voltage settings are plotted in Figure 3. The data points for any one of the lines labelled A, B, C, D, and E were obtained by varying the input pressure to the transducer (80, 100, or 120 mm Hg) while maintaining a constant balance voltage. Each separate line refers to a different balance voltage setting. The voltages selected for these examples were 48.7, 47.0, 46.0, 45.3, and 44.3 mv. These voltages cover the range of voltages used during the experiment.

Figure 3. A graph of pulses/sec as a function of blood pressure. The five lines labelled A through E represent different balance voltages as indicated.

Figure 3


Balance Voltage Settings (mv)
A -- 48.7
B -- 47.0
C -- 46.0
D -- 45.3
E -- 44.3
A
B
C
D
E
200
160
120
80
40
0
PULSES / SEC
0
40
80
120
PRESSURE (mm Hg)

From this figure, it is clear that the relationship between pulses/sec and mm Hg was linear regardless of the balance voltage employed. In addition, the number of pulses/sec corresponding to a given change in pressure was the same at each balance-voltage setting. For example, line D on Figure 3 shows that the number of pulses/sec corresponding to 80 mm Hg was 20 and that corresponding to 200 mm Hg was 70. The difference between the two values was 50. On the other hand, line A reveals that the number of pulses/sec corresponding to 80 mm Hg and 100 mm Hg were 120 and 170, respectively. Again the difference was 50. Hence, it should be noted the sole effect of changing the balance-voltage settings was to increase or decrease the absolute size of the pulses/sec number corresponding to a given level of blood pressure.

Inasmuch as the number of pulses/sec corresponding to a given pressure varied as a function of the balance voltage, it was necessary to standardize the blood-pressure scores of each rat by using the following procedure. The general equation defining a linear relationship between two variables, x and y, is

$$y = ax + b \text{ (slope-intercept form)} \quad (1).$$

In the present case, blood pressure in mm Hg (x) was directly proportional to pulses/sec (y). The two constants, a and b, were determined by the following equations:

$$a = \frac{dy}{dx} \quad \text{(i.e. slope)} \qquad (2).$$

and

$$b = y - ax \qquad (3).$$

In equation (2) the slope of the line is expressed in terms of a

change in y with respect to x. The y-intercept, b, in equation (3) is the point where the line intersects the y-axis. Equation (3) is derived from equation (1). To solve equations (2) and (3), pulses/sec scores corresponding to specific mm Hg pressure values were necessary. These values were provided by the calibration procedure described above that was performed on each animal at the end of a conditioning session.

As an example illustrating how the pulses/sec scores were transformed into mm Hg pressure, consider the data from line D in Figure 3. Note that a pulses/sec score of 120 corresponded to 120 mm Hg and that a score of 70 corresponded to 100 mm Hg. By substitution of these values into equations (2) and (3), the slope (a) and y-intercept (b) are given by,

$$a = \frac{120 - 70}{120 - 100} = 2.5,$$

and

$$b = 120 - 2.5\ (120) = -180.$$

Once a and b were determined for a particular animal, the transformation of pulses/sec scores into mm Hg was accomplished by utilization of a derivation of equation (1). Thus, if 100 pulses/sec was the score punched on the paper tape, then the solution to equation (1) became

$$x = \frac{100 + 180}{2.5} = 112 \text{ mm Hg.}$$

This meant that, for the particular balance voltage used, 100 pulses/sec corresponded to a pressure of 112 mm Hg. It should be noted that the balance voltage used in this example (45.3 mv) was the same as that employed for approximately 93% of the rats.

RESULTS

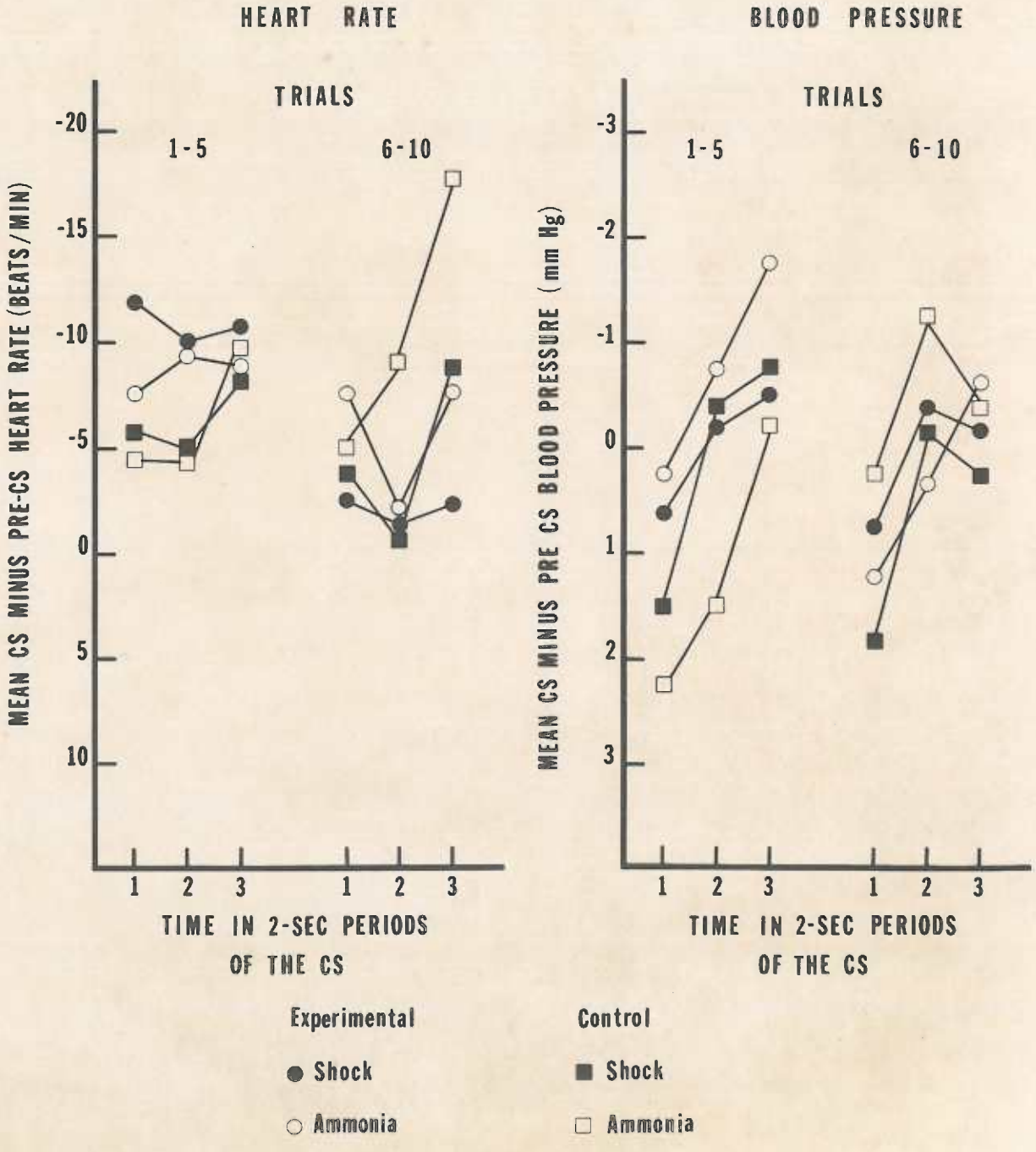
Preconditioning trials with the CS alone

On the left side of Figure 4, the mean CS minus pre-CS responses of each of the four groups are depicted in successive 2-sec periods of the CS averaged over two blocks of five preconditioning trials each. With respect to this part of the figure, it is clear that the dominant heart-rate responses to the novel CS were cardiodecelerations. A 2 x 2 x 2 x 3 (experimental vs control x type of US x trial blocks x counting periods) analysis of variance contained a significant counting periods effect, F (2,88) = 4.04, $p < .05$ indicating that the overall change in heart rate during the CS was reliable. The analysis also provided a significant experimental vs control x trial blocks interaction, F (1,44) = 4.28, $p < .05$. This outcome can be accounted for on the basis of chance differences between the experimental and control groups, inasmuch as no experimental manipulations had been made at this point in the experiment.

The mean CS minus pre-CS blood-pressure responses of each group in successive 2-sec periods of the CS averaged over two blocks of five preconditioning trials each are presented on the right side of Figure 4. In general, the CS in the first block of trials elicited a biphasic response consisting of an increase in blood pressure during the first 2-sec period followed by a decrease in pressure by the third 2-sec period. During the second block of trials, the biphasic nature of the response was less apparent in that the decrease in blood pressure in the third 2-sec period was reduced in magnitude. In a 2 x 2 x 2 x 3

Figure 4. Mean CS minus pre-CS blood-pressure responses of the shock experimental, ammonia experimental, shock control, and ammonia control groups in each 2-sec period of the CS averaged across two blocks of five preconditioning trials each.

Figure 4


HEART RATE
BLOOD PRESSURE
TRIALS
1-5
6-10
MEAN CS MINUS PRE-CS HEART RATE (BEATS/MIN)
-20
-15
-10
-5
0
5
10
MEAN CS MINUS PRE CS BLOOD PRESSURE (mm Hg)
-3
-2
-1
0
1
2
3
1 2 3 1 2 3
TIME IN 2-SEC PERIODS OF THE CS
Experimental
● Shock
○ Ammonia
Control
■ Shock
□ Ammonia

(experimental vs control x type of US x trial blocks x counting periods)analysis of variance, a significant counting periods effect, F (2,88) = 20.28, $p < .001$ was demonstrated, indicating that the overall change in blood pressure during the CS was reliable. There was also a significant trial blocks x counting periods interaction, F (2, 88) = 5.87, $p < .01$ indicating that there was a reliable change in the form or topography of the blood-pressure response across the two trial blocks. In addition, there was a significant experimental vs control x type of US x trial blocks interaction, F (1,44) = 4.76, $p < .05$ and a significant experimental vs control x type of US x trial blocks interaction, F (1,44) = 6.00, $p < .01$. The two interactions can be attributed to chance differences in the mean blood-pressure reactions of the groups to the CS, because at this point in the experiment differential treatments had not been administered to the groups.

A further test of the reliability of the blood-pressure responses on the pretest trials was achieved by comparing the means of the first and third periods of the CS on each trial block against zero using separate t-tests. These tests were performed on the combined data of the groups after a Newman-Keuls analysis indicated that there were no significant differences between the groups during these time periods. The tests established that during the first trial block there was a significant increase in blood pressure in the first counting period, t (47) = 2.87, $p < .005$, and a significant decrease in the third counting period, t (47) = 3.82, $p < .005$. During the second trial block, the increase in pressure during the first counting period was

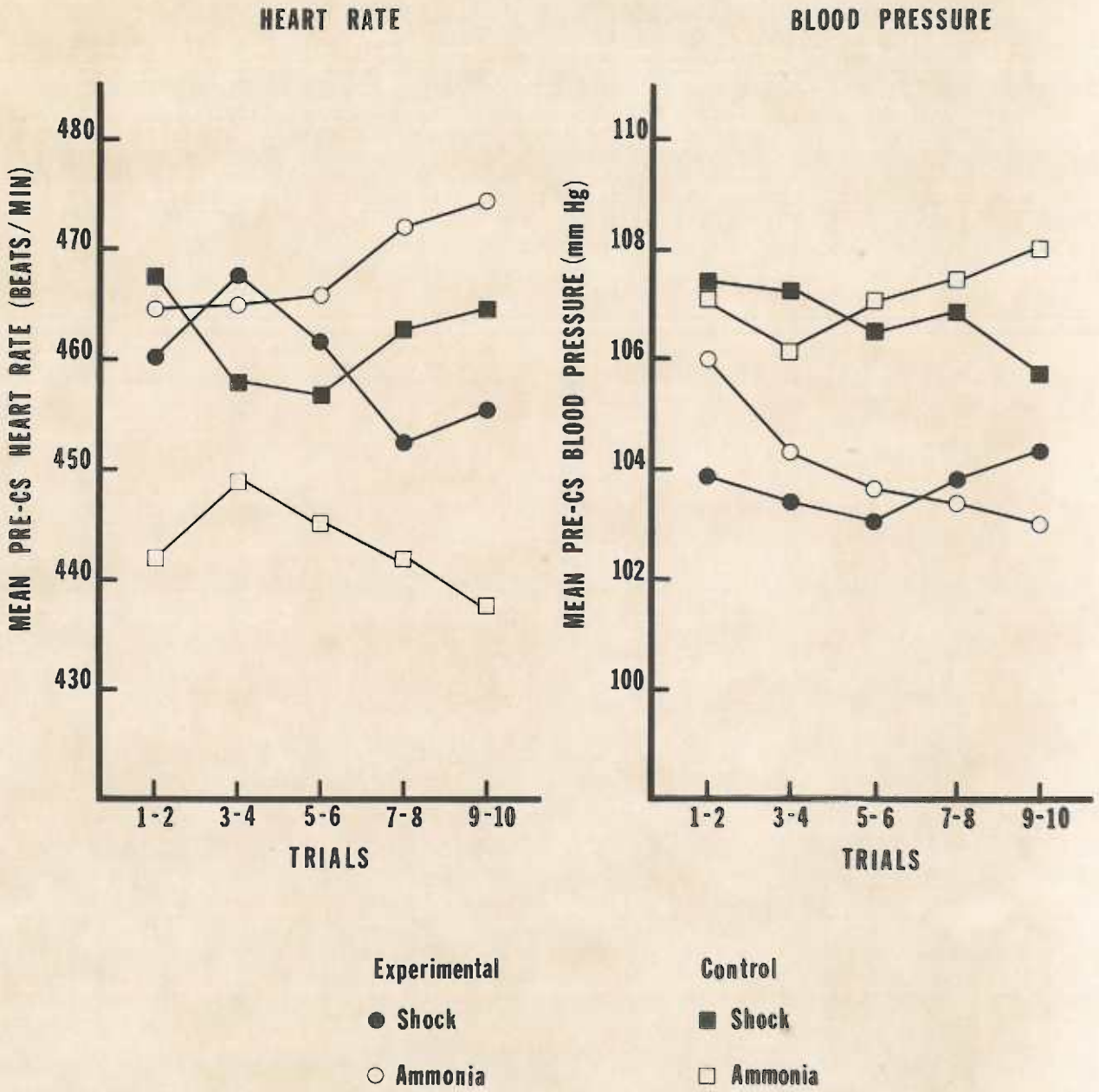
still significant, t (47) = 3.51, $p < .005$, whereas the decrease in the third period was not significant. These outcomes provide further statistical support for the reliability of the visually apparent findings that the topography of the blood-pressure response to the initial presentation of the CS was biphasic, and that the primary change in the topography of the response across trials occurred in the third counting period.

The mean pre-CS heart rates of each group during the pretest phase of the experiment are illustrated on the left side of Figure 5. These data are plotted in five successive blocks of two trials each. In general, the pre-CS heart rates were relatively stable over trials. Although the ammonia control group appeared to have lower basal heart-rate levels than the other groups, a 2 x 2 x 5 (experimental vs control x type of US x trial blocks) analysis of variance provided no significant outcomes.

On the right side of Figure 5, the mean pre-CS blood-pressure levels of each group on the pretest trials are pictured averaged over five blocks of two trials each. This part of the figure indicates that the baseline blood-pressure levels of the two control groups were consistently higher than those of the experimental groups. However, the only significant outcome of a 2 x 2 x 5 (experimental vs control x type of US x trial blocks) analysis of variance was that of an experimental vs control x type of US x trial blocks interaction, F (4,170) = 3.9, $p < .01$. This interaction can be viewed as resulting from chance differences between the groups, as all groups had been treated similarly up to this point in the experiment.

Figure 5. Mean pre-CS heart rate and blood-pressure levels of the shock experimental, ammonia experimental, shock control, and ammonia control groups averaged over five successive blocks of two preconditioning trials each.

Figure 5


HEART RATE
MEAN PRE-CS HEART RATE (BEATS/MIN)
480
470
460
450
440
430
1-2
3-4
5-6
7-8
9-10
TRIALS
BLOOD PRESSURE
MEAN PRE-CS BLOOD PRESSURE (mm Hg)
110
108
106
104
102
100
1-2
3-4
5-6
7-8
9-10
TRIALS
Experimental
Shock
Ammonia
Control
Shock
Ammonia

To provide a measure of the degree to which changes in heart rate were related to changes in blood pressure during the preconditioning trials, a series of Spearman rank-order correlation analyses were performed on the heart rate and blood-pressure responses of each group during corresponding time periods of the CS. The data for these tests were difference scores from each 2-sec period of the CS averaged over two blocks of five trials each. The r values from the Spearman tests on these means are illustrated in Table 1. An inspection of this table reveals that, of the eight tests that were carried out on each counting period, only three were significant on the first counting period, and just one was significant on the third counting period. In the case of the first counting period, the significant correlations meant that large increases in blood pressure were associated with large decreases in heart rate. The single significant correlation in the third counting period was the result of large decreases in blood pressure being associated with large decreases in heart rate.

Table 1. Spearman rank-order correlations between heart rate and blood-pressure responses during the three periods of the CS averaged over two blocks of five preconditioning trials each. An asterisk denotes which correlations were significant.

Group	Trials	Periods of the CS 1	2	3
Shock Experimental	1-5	+ .33	+ .34	+ .34
	6-10	+ .06	+ .01	+ .48
Ammonia Experimental	1-5	- .72*	+ .49	+ .20
	6-10	- .60*	+ .28	- .02
Shock Control	1-5	- .64*	- .03	+ .51*
	6-10	- .11	- .10	+ .04
Ammonia Control	1-5	+ .04	+ .20	+ .38
	6-10	- .48	- .36	- .18

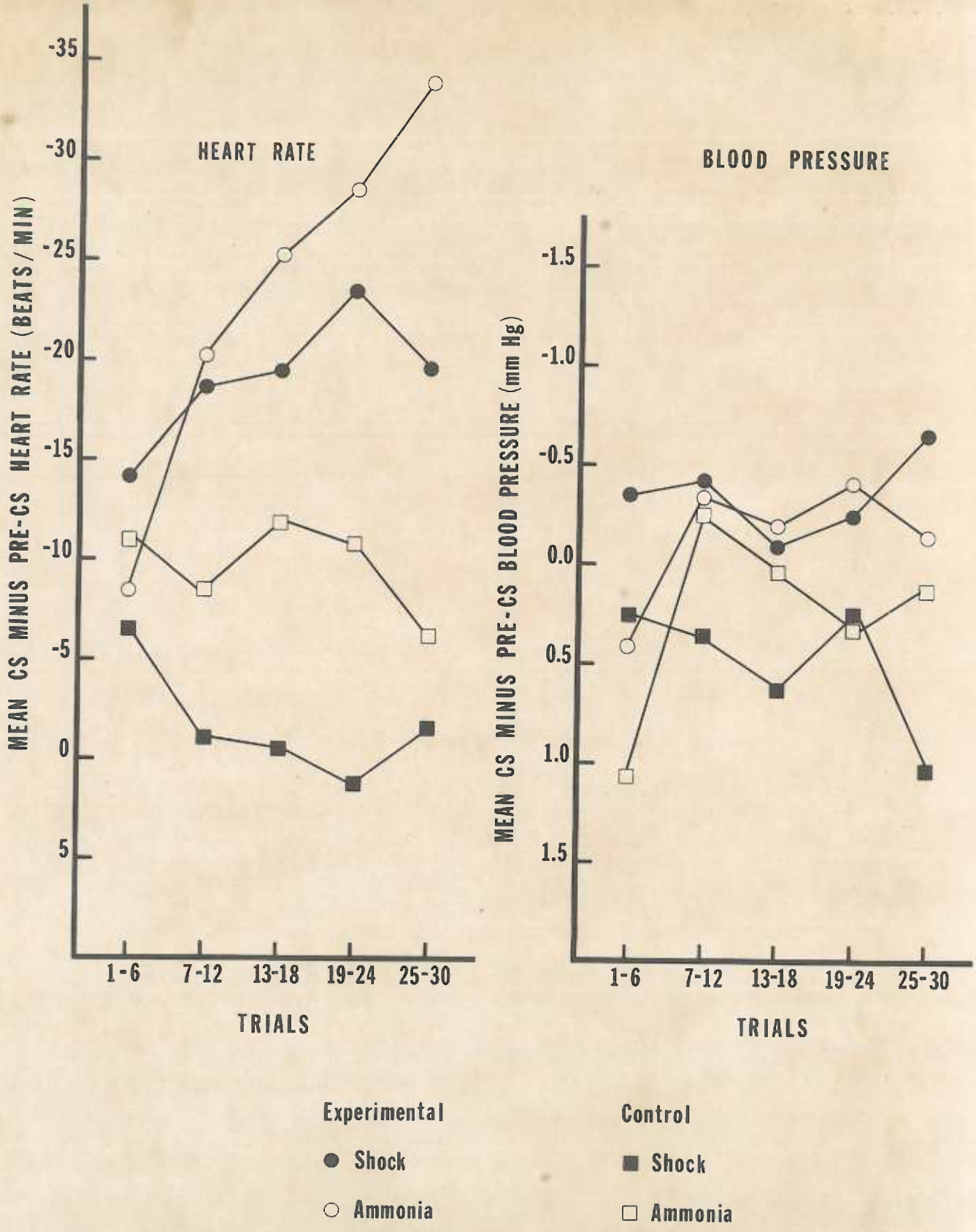
* $p<.05$

Acquisition

Diagrammed on the left portion of Figure 6 are the mean CS minus pre-CS heart-rate responses of each group averaged over five successive blocks of six acquisition trials each. An inspection of this part of the figure reveals that both experimental groups displayed cardio-decelerative conditioned responses which increased in magnitude across trial blocks. The response exhibited by the ammonia experimental group seemingly developed at a faster rate and attained a higher terminal level than that of the shock experimental group. The two control groups also displayed predominantly decelerative heart-rate responses during acquisition training with the magnitudes of their responses in the first trial block being comparable to those of the experimental groups. On subsequent trial blocks, the magnitudes of the reactions of the shock control group dropped rapidly to near zero, whereas those of the ammonia control group remained elevated throughout acquisition. A 2 x 2 x 5 (experimental vs control x type of US x trial blocks) analysis of variance showed that the overall difference between the experimental and control groups was significant, F (1,44) = 33.35, $p < .001$. There was also a significant type of US effect, F (1,44) = 5.97, $p < .05$, indicating that the overall difference between the combined experimental and control ammonia groups and the combined experimental and control shock groups was reliable. In addition, there was a significant trial blocks effect, F (4,176) = 4.07, $p < .01$, and a significant experimental vs control x trial blocks interaction, F (4,176) = 12.43, $p < .001$, providing further statistical support for

Figure 6. Mean CS minus pre-CS heart rate and blood-pressure responses during the 6-sec CS averaged over five successive blocks of six acquisition trials each for the shock experimental, ammonia experimental, shock control and ammonia control groups.

Figure 6


HEART RATE
MEAN CS MINUS PRE-CS HEART RATE (BEATS/MIN)
-35
-30
-25
-20
-15
-10
-5
0
5
1-6
7-12
13-18
19-24
25-30
TRIALS
BLOOD PRESSURE
MEAN CS MINUS PRE-CS BLOOD PRESSURE (mm Hg)
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
1-6
7-12
13-18
19-24
25-30
TRIALS
Experimental
Shock
Ammonia
Control
Shock
Ammonia

the presence of successful heart-rate conditioning. A significant type of US x trial blocks interaction, F (4, 176) = 2.61, $p < .05$, established that the heart-rate responses of the combined ammonia groups changed across trials in a way which was different from that shown by the combined shock groups. Finally, there was a significant experimental vs control x type of US x trial blocks interaction, F (4, 176) = 2.61, $p < .05$, indicating that the ammonia and shock USs had different effects on the heart-rate responses of the experimental and control groups. A subsequent analysis of variance carried out on just the data of the two experimental groups provided a significant trial blocks effect, F (4, 88) = 14.44, $p < .001$, and a significant type of US x trial blocks interaction, F (4, 88) = 4.00, $p < .001$, establishing that the conditioned responses of the shock and ammonia experimental groups developed at different rates across acquisition trials. The same analysis performed on the two control groups provided only a significant type of US effect, F (1, 22) = 8.74, $p < .01$, indicating that the overall magnitudes of the heart-rate responses of the two control groups were reliably different from each other.

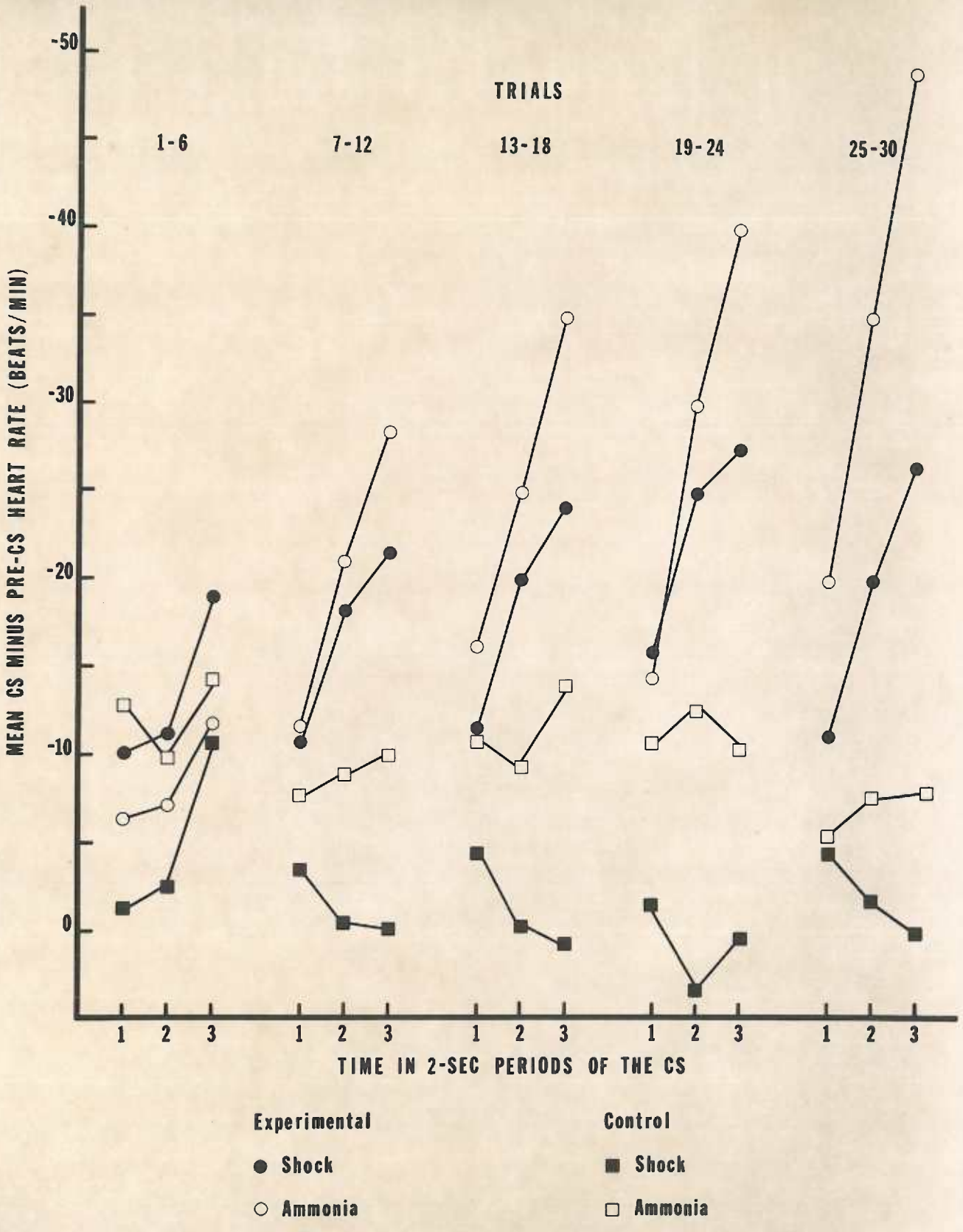
Shown on the right side of Figure 6 are the mean CS minus pre-CS blood-pressure responses of the experimental and control groups during acquisition. The difference scores for each group were averaged over five successive blocks of six trials each. From an examination of this part of the figure, it appears that, in general, the blood-pressure responses of the two experimental groups were small overall decreases in pressure ($\overline{X}$ = -.25 mm Hg). The responses of the control groups, on

the other hand, appeared to be small overall increases in pressure ($\overline{X}$ = +.45 mm Hg). In neither case did the magnitudes of the responses appear to change substantially over the acquisition trials. However, as will be shown below, a single average of the blood-pressure scores of the three, 2-sec periods of the CS-US interval as presented in Figure 6 is not representative of the blood-pressure reactions that occurred during conditioning as these reactions were clearly biphasic in nature containing both increases and decreases in pressure. Nevertheless, a 2 x 2 x 5 (experimental vs control x type of US x trial blocks) analysis of variance on the blood-pressure results in Figure 6, provided a significant experimental vs control effect, F (1,44) = 4.87, $p < .05$.

The data plotted in Figure 7 provide a detailed composite of the form or topography of the heart-rate responses of the experimental and control groups in three successive 2-sec segments of the CS averaged over five blocks of six trials each. An inspection of these results indicates that the topographies of the responses of the experimental and control groups were similar during the first block of trials. In both cases, there was a tendency for cardiodecelerations to be larger toward the end of the CS than at the beginning of the CS. During succeeding trial blocks, this same basic form persisted in the experimental groups with the overall magnitude of the reactions in each counting period of the CS increasing over trials. It also appears that the growth in the magnitude of the heart-rate decelerations of the experimental groups was more pronounced in the third than in the first counting period of the CS.

Figure 7. Mean CS minus pre-CS heart-rate responses of the shock experimental, ammonia experimental, shock control, and ammonia control groups in each 2-sec period of the CS averaged across five blocks of six acquisition trials each.

Figure 7

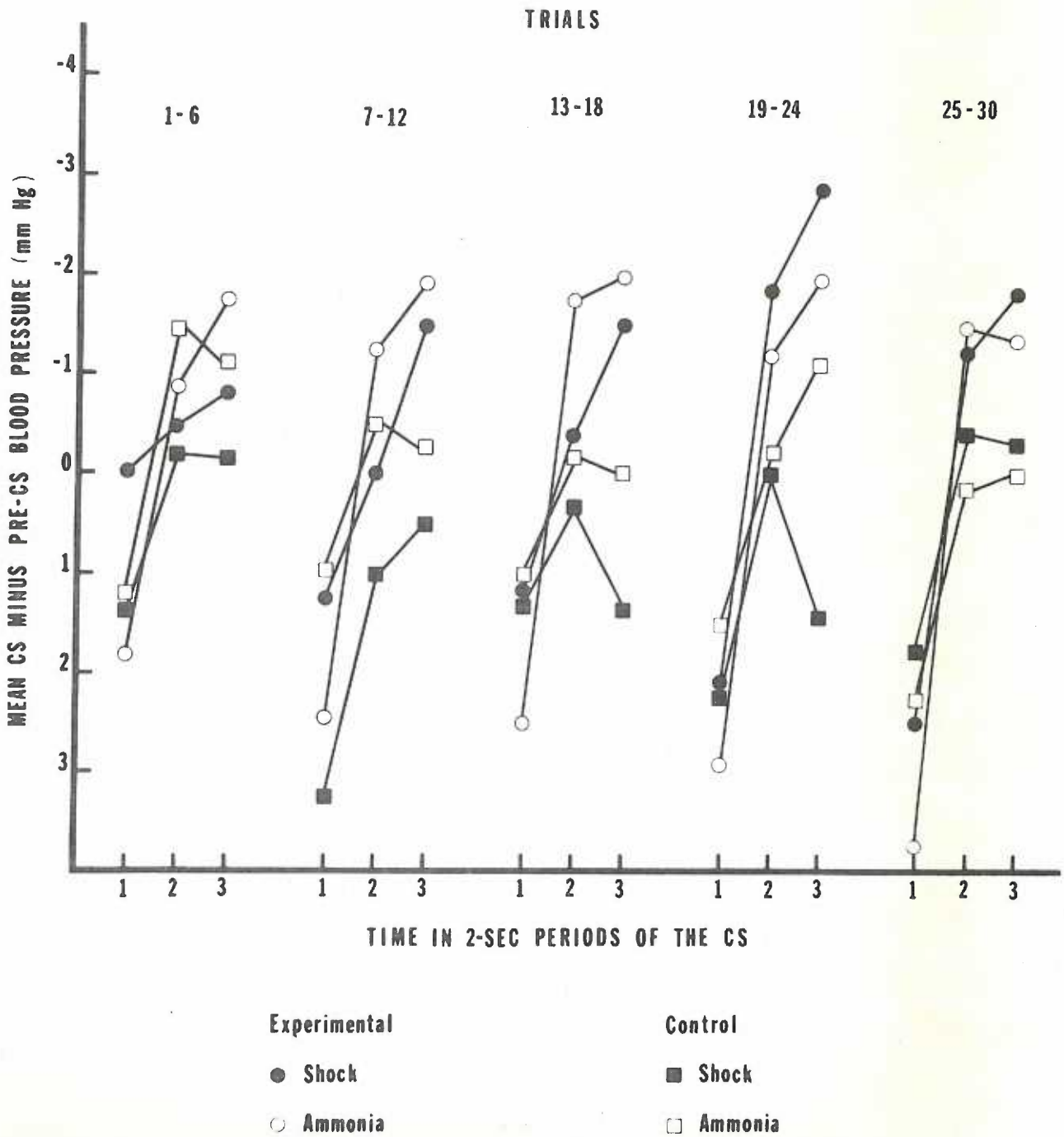

TRIALS
1-6
7-12
13-18
19-24
25-30
-50
-40
-30
-20
-10
0
MEAN CS MINUS PRE-CS HEART RATE (BEATS/MIN)
1 2 3 1 2 3 1 2 3 1 2 3 1 2 3
TIME IN 2-SEC PERIODS OF THE CS
Experimental
Shock
Ammonia
Control
Shock
Ammonia

Thus, from the first to the last trial block, the mean increase in the magnitude of the cardiodecelerations of the experimental groups was 115% in the first counting period and 178% in the third counting period. In terms of the response topographies of the control groups, there was little evidence in the initial block of trials of a heart-rate response in the group that received the shock US. On the other hand, the ammonia control group exhibited heart-rate decelerations in the three counting periods of the CS that had approximately the same magnitude. A 2 x 2 x 5 x 3 analysis of variance was carried out on the heart-rate data shown in Figure 7. The between-subjects factors were experimental vs control and type of US, and the within-subjects factors, trial blocks and counting periods. Only within-subjects outcomes pertaining to the topographies of the heart-rate responses will be reported. There was a significant counting periods effect, F (2, 88) = 23.55, $p < .001$, and a significant experimental vs control x counting periods interaction, F (2, 88) = 21.22, $p < .001$, indicating that the response topographies of the experimental and control groups were reliably different, and a significant experimental vs control x trial blocks x counting periods interaction F (8, 352) = 3.28, $p < .01$, establishing that the topographies of the experimental and control groups changed differentially across trials.

As can be seen from Figure 8, the mean CS minus pre-CS blood-pressure responses of the experimental and control groups are plotted in three successive 2-sec periods of the CS averaged over five blocks of six acquisition trials each. In general, the responses of the experimental and control groups in the first block of six trials were similar. Three of the four groups displayed a biphasic response consisting of an increase in blood pressure in the first counting period of the CS followed by a decrease in pressure in the second and third counting periods. On succeeding trial blocks, both experimental groups demonstrated an increase in the magnitude of the blood-pressure elevations to the onset of the CS. On the last trial block the blood-pressure increase in the first counting period reached +2.5 mm Hg for the experimental shock group and +3.9 mm Hg for the experimental ammonia group. The blood-pressure decreases occurring in the second and third counting periods also became larger across trial blocks in the experimental groups reaching approximately -2.0 mm Hg in each case toward the end of conditioning. In contrast to what was found for heart rate, the figure provides no evidence that the type of US influenced either the magnitude or the topography of the blood-pressure responses of the experimental groups. With respect to the two control groups, the blood-pressure increase in the initial counting period on the first trial block persisted or possibly even increased across subsequent trial blocks. However, neither control group demonstrated a consistent decrease in blood pressure during the second and third counting periods. Moreover, those decreases which were evident were substantially smaller in magnitude than those exhibited by the experimental

Figure 8. Mean CS minus pre-CS blood-pressure responses of the shock experimental, ammonia experimental, shock control, and ammonia control groups in each 2-sec period of the CS averaged across five blocks of six acquisition trials each.

Figure 8


TRIALS
1-6
7-12
13-18
19-24
25-30
MEAN CS MINUS PRE-CS BLOOD PRESSURE (mm Hg)
-4
-3
-2
-1
0
1
2
3
1 2 3
TIME IN 2-SEC PERIODS OF THE CS
Experimental
Shock
Ammonia
Control
Shock
Ammonia

groups. A 2 x 2 x 5 x 3 (experimental vs control x type of US x trial blocks x counting periods) analysis of variance identical to that which was used for heart rate was carried out on the blood-pressure difference scores shown in Figure 8. Only those within-subjects outcomes pertaining to response topography will be reported. There was a significant counting periods effect, F (2,88) = 71.33, $p < .001$, revealing that the overall change in the blood-pressure response to the CS was reliable for the combined groups. A significant counting periods x trial blocks interaction, F (8, 352) = 3.73, $p < .001$, indicated that the form or topography of the response changed reliably as a function of trials. There was a significant experimental vs control x counting periods interaction F (2, 88) = 9.23, $p < .005$, establishing that the topographies of the blood-pressure responses of the experimental and control groups were reliably different. There was also a significant experimental vs control x counting periods x trial blocks interaction, F (8, 352) = 3.16, $p < .001$, showing that the development of the response topographies of the experimental and control groups was reliably different. These last two significant interactions provide statistical support for the presence of successful conditioning in establishing that the blood-pressure reactions elicited by the CSs in the experimental and control treatment conditions were reliably different.

In order to provide more detailed information on the way in which the blood-pressure responses to the CS developed during the acquisition trials, separate t-tests were carried out on the mean difference-score

responses of the combined experimental and control groups during each of the three periods of the CS. In these tests each blood-pressure response was tested against zero. The outcomes of these tests along with the mean blood-pressure changes of the groups are presented in Table 2. This table provides statistical evidence of a reliable biphasic response for the combined experimental group in all but the first trial block. Thus, on trial blocks 2 through 5 the experimental groups showed significant blood-pressure increases in the first counting period followed by significant blood-pressure decreases in the second and third counting periods. On the other hand, only in the initial trial block did the control groups demonstrate evidence of a reliable biphasic response to the CS. In this case a significant blood-pressure increase in the first counting period was followed by significant blood-pressure decreases in the second and third counting periods. During subsequent trial blocks, the control groups continued to show significant blood-pressure increases to CS-onset and non-significant fluctuations during later portions of the CS.

Separate t-tests established that there were no reliable differences between the experimental and control groups during any of the counting periods in the first block of trials or during the first period of the CS in any of the later blocks of trials. However, the blood-pressure decreases of the experimental groups were significantly larger than the reactions of the control group during the second period of the CS in the final three trial blocks and during the third period of the CS in the final four trial blocks. On the basis of these out-

Table 2. Mean blood-pressure changes in mm Hg during the three periods of the CS averaged across five blocks of six trials each. The data were collapsed across the type of US factor to form combined experimental and control groups. Those means which were significantly different from zero are denoted with an asterisk.

COMBINED EXPERIMENTAL GROUPS

Trial Blocks	Periods of the CS 1	2	3
1-6	+ .90	- .65	-1.30*
7-12	+1.95*	- .65	-1.70*
13-18	+1.95*	-1.10*	-1.70*
19-24	+2.55*	-1.80*	-2.45*
25-30	+3.15*	-1.40*	-1.55*

COMBINED CONTROL GROUPS

Trial Blocks	Periods of the CS 1	2	3
1-6	+1.25*	- .85*	- .70*
7-12	+2.05*	+ .30	+ .15
13-18	+1.20*	+ .05	+ .65
19-24	+1.80*	- .10	+ .20
25-30	+1.95*	- .25	- .15

* $p<.05$

comes, it would appear that blood-pressure conditioning was restricted mainly to later portions of the CS-US interval, and that the conditioned response was a decrease in pressure. A careful examination of the data presented in Table 2 will also show that the significant differences between the experimental and control groups that occurred for the second and third counting periods late in acquisition were due to the combination of the blood-pressure decreases in the experimental group becoming larger at the same time that the decreases in the control group were becoming smaller.

In order to help illuminate the nature of the differences of the blood-pressure reactions elicited by the CS in the experimental and control groups, polygraph tracings of single acquisition trials were selected for animals in the ammonia experimental and ammonia control groups. These tracings are reproduced in Figures 9 and 10. Starting at the top of these figures, the first line represents the ECG counting spikes and time marks, the second the CS and US time marks, the third the ECG, and the fourth continuous blood pressure. Next to the blood pressure tracings on the right are shown the blood pressure calibration levels in mm Hg. Figure 9 shows clearly the biphasic nature of the blood-pressure reaction elicited by the CS in the experimental groups. With the onset of the CS, blood pressure increased rapidly reaching its peak level near the end of the first 2-sec period. The pressure then began to fall going below baseline during the second and third counting periods. In this case, the lowest level occurred at the beginning of the third counting period. In contrast, the blood-pressure reaction

Figure 9. Polygraph record (trial 10) of a rat in the ammonia experimental group. The first line contains the ECG counting spikes and timing marks, the second the CS and US intervals, the third the ECG, the fourth arterial blood pressure in mm Hg, the fifth the CS and US intervals.

Figure 9

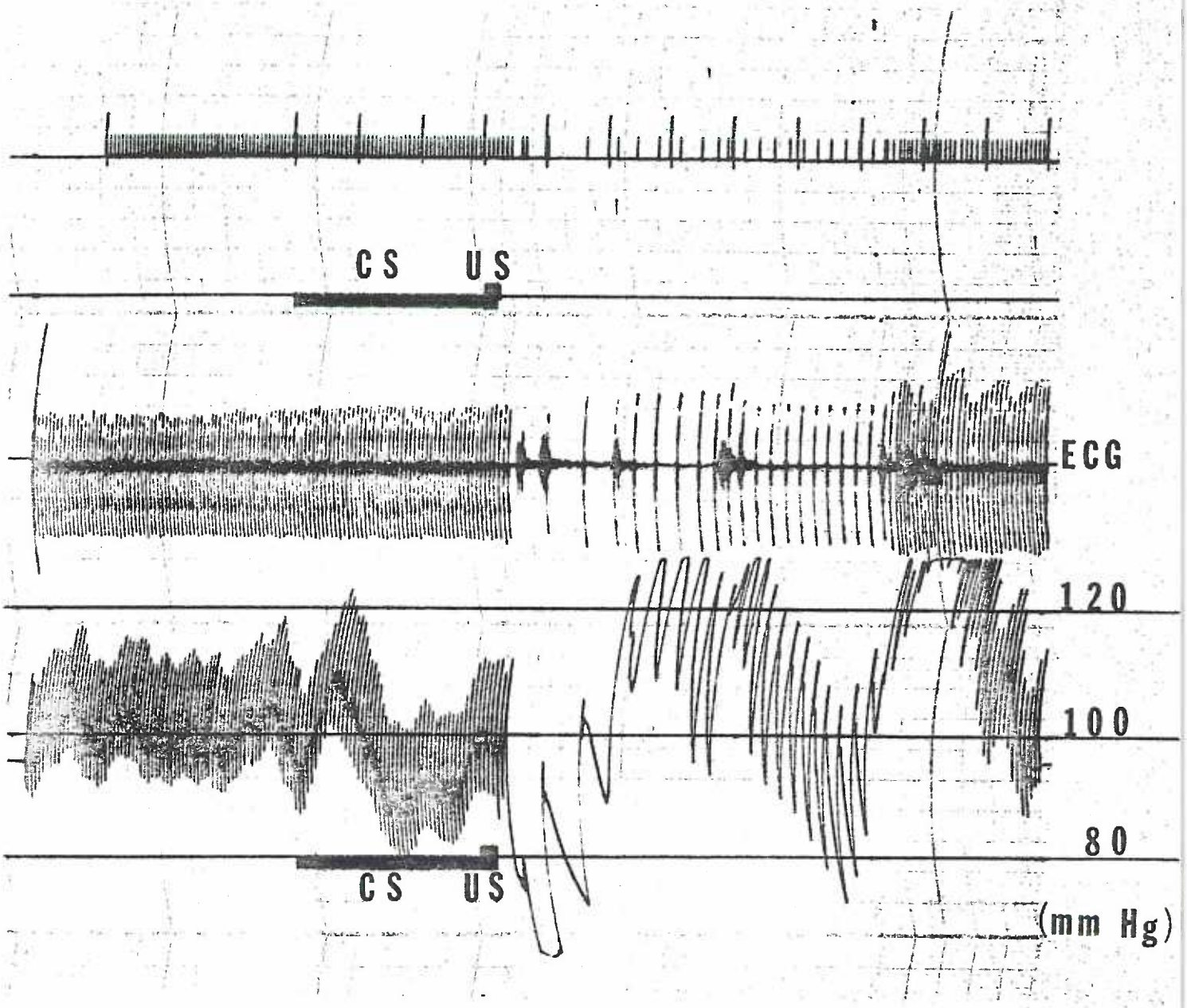
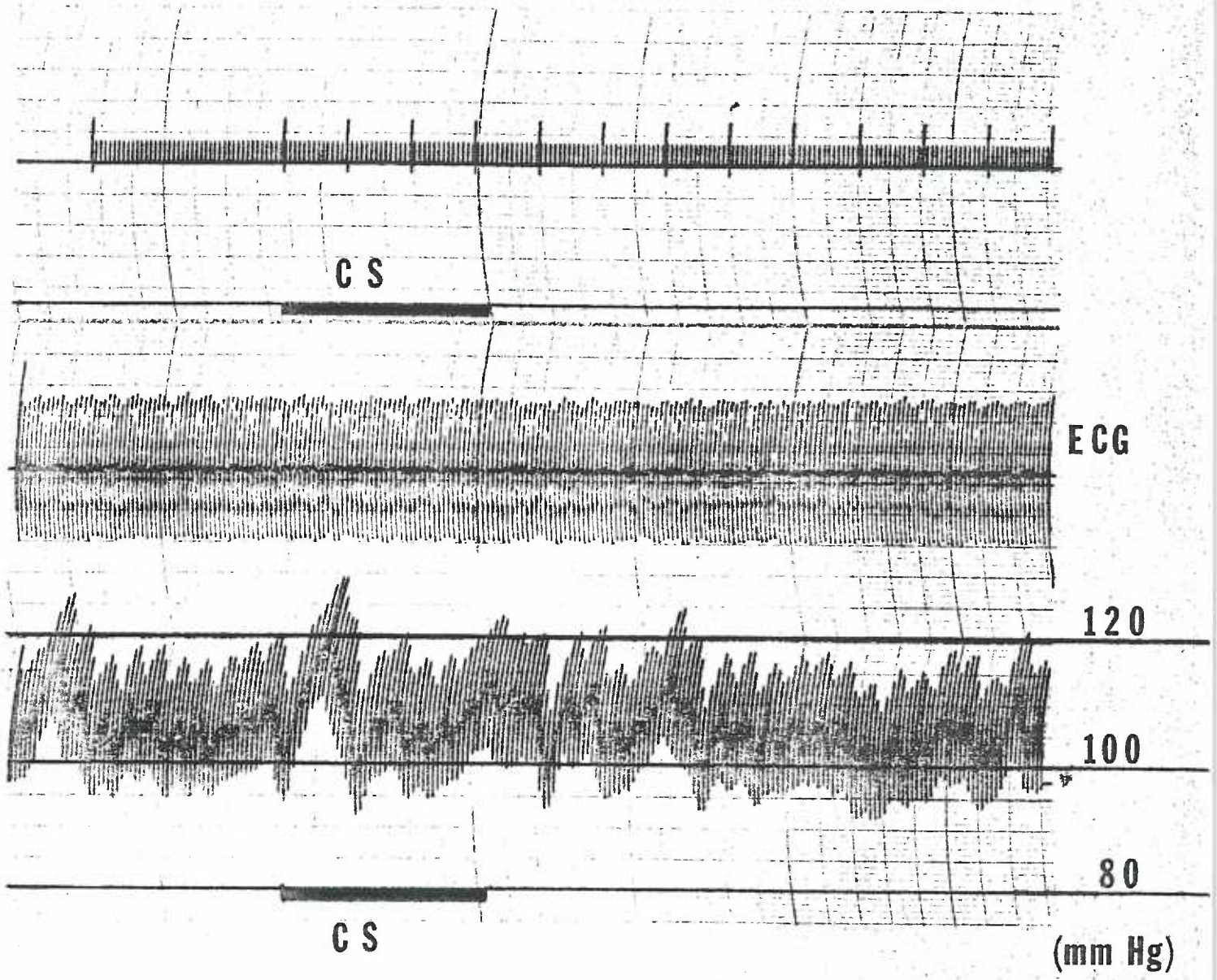


Figure 10. Polygraph record (trial 28) of a rat in the ammonia control group. The first line contains the ECG counting spikes and timing marks, the second the CS and US intervals, the third ECG, the fourth arterial blood pressure in mm Hg, the fifth CS and US intervals.

Figure 10



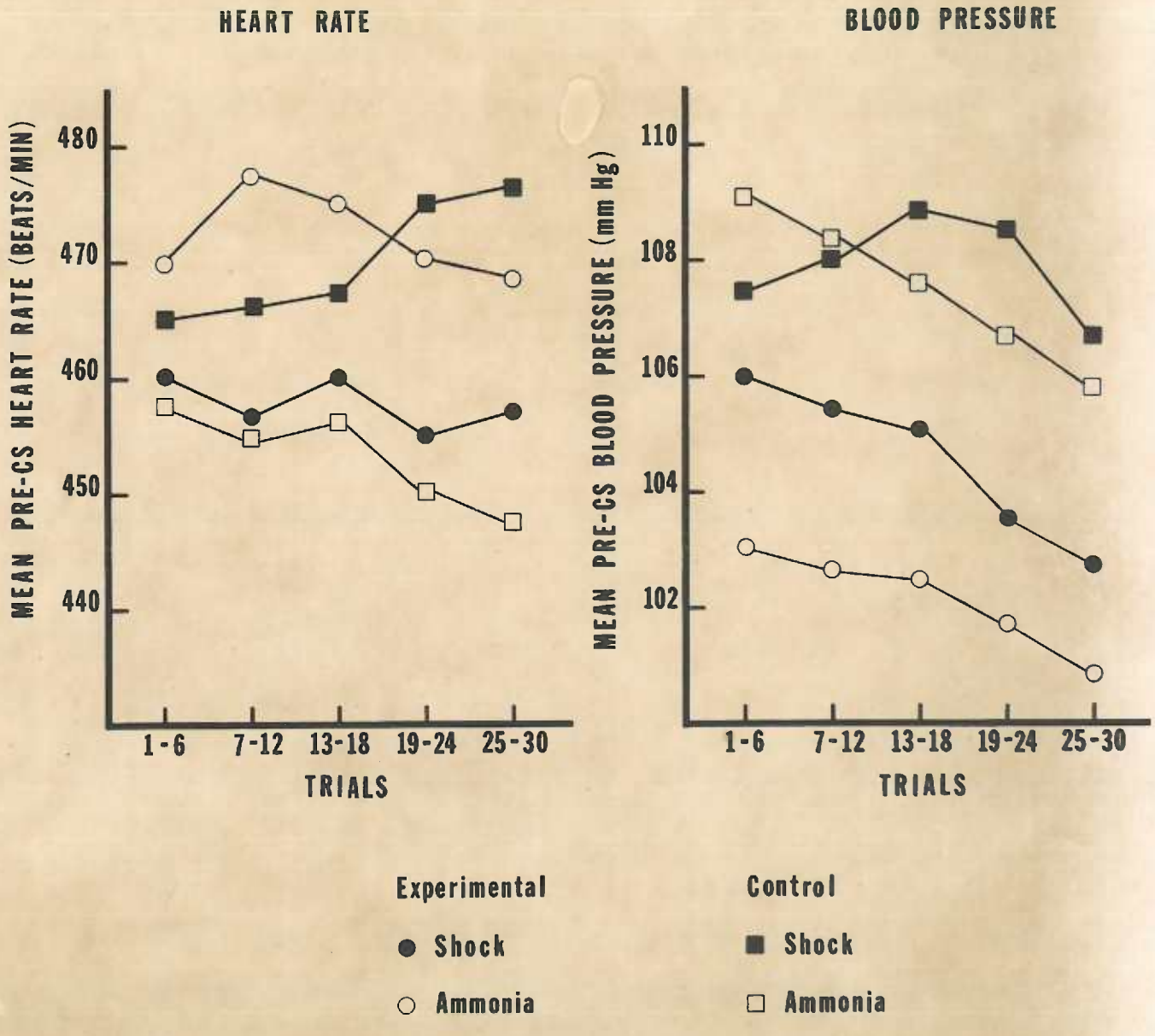
of the control animal exhibited in Figure 10 shows an initial elevation to CS onset with the pressure then returning to but not going below baseline during later portions of the CS. It should also be clear, from an inspection of these figures, that peak blood-pressure increases and decreases to the CS would be expected to be somewhat greater than the average values generated by the online blood-pressure recording system that was used in the present experiment.

The mean pre-CS heart-rate levels of each group during acquisition are shown on the left portion of Figure 11. The levels are presented in five successive blocks of six trials each. This figure shows that three of the four groups demonstrated slight decreases in baseline heart rate across trials, whereas the fourth group demonstrated a slight increase. However, a 2 x 2 x 5 (experimental vs control x type of US x trial blocks) analysis of variance did not yield any significant outcomes.

Pictured on the right side of Figure 11 are the pre-CS blood-pressure levels of each group during acquisition training in five successive blocks of six trials each. It may be seen from this figure that the three groups showing declines in baseline heart rate also showed decreases in baseline blood pressure over the course of acquisition. In addition, blood-pressure levels of the two control groups were consistently higher than those of the two experimental groups. In a 2 x 2 x 5 (experimental vs control x types of US x trial blocks) analysis of variance, the difference between the experimental and control groups was significant, F (1, 44) = 8168, $p < .01$, as was the change in blood pressure across trials, F (4, 176) = 7.74, $p < .001$.

Figure 11. Mean pre-CS heart-rate and blood-pressure levels of the shock experimental, ammonia experimental, shock control, and ammonia control groups averaged over five blocks of six acquisition trials each.

Figure 11


HEART RATE
MEAN PRE-CS HEART RATE (BEATS/MIN)
480
470
460
450
440
1-6
7-12
13-18
19-24
25-30
TRIALS
BLOOD PRESSURE
MEAN PRE-CS BLOOD PRESSURE (mm Hg)
110
108
106
104
102
1-6
7-12
13-18
19-24
25-30
TRIALS
Experimental
Shock
Ammonia
Control
Shock
Ammonia

To provide a measure of the relation between heart rate and blood pressure during the acquisition trials, a series of Spearman rank-order correlation analyses were performed on the mean responses of each group during corresponding time periods of the CS. Difference scores from each 2-sec period of the CS, averaged over the 30 acquisition trials, provided the data for these analyses. The correlation values from the tests are displayed on the top of Table 3. Here, only two of 12 correlations were significant, with each one occuring in the third period of the CS. The significant correlation in the ammonia experimental group meant that large decreases in heart rate were associated with small increases or decreases in blood pressure. In the case of the ammonia control group, large decreases in heart rate were associated with large decreases in blood pressure.

Based on the assumption that the magnitude of the increases in blood pressure during the first CS period might be related to the magnitude of the decreases in heart rate during the third CS period, Spearman rank-order correlations were carried out on the blood-pressure and heart-rate responses during these periods of the CS. The analyses on the differences scores averaged across the 30 acquisition trials provided no significant results. A similar series of correlations performed on difference scores averaged over five successive blocks of six trials each indicated that only two of 20 correlations were significant.

The middle portion of Table 3 contains the Spearman rank-order correlations between pre-CS blood pressure and blood-pressure changes during each period of the CS averaged across all acquisition trials.

Table 3. Spearman rank-order correlations between heart rate and blood pressure responses during the three periods of the CS averaged over all 30 acquisition trials. Three separate series of correlations were performed: (1) heart rate responses vs blood pressure responses, (2) pre-CS blood pressure vs blood pressure responses, and (3) pre-CS heart rate vs heart rate responses. Significant correlations are designated with an asterisk.

HEART-RATE RESPONSES VS BLOOD-PRESSURE RESPONSES

Group	Periods of the CS 1	2	3
Shock Experimental	- .46	- .22	+ .40
Ammonia Experimental	- .04	- .24	- .50*
Shock Control	+ .08	- .19	+ .21
Ammonia Control	+ .20	+ .22	+ .56*

PRE-CS BLOOD PRESSURE VS BLOOD-PRESSURE RESPONSES

Group	Periods of the CS 1	2	3
Shock Experimental	+ .67*	- .08	- .25
Ammonia Experimental	+ .29	- .14	+ .12
Shock Control	- .06	+ .26	- .23
Ammonia Control	- .16	+ .16	+ .15

PRE-CS HEART RATE VS HEART-RATE RESPONSES

Group	Periods of the CS 1	2	3
Shock Experimental	- .11	- .01	+ .01
Ammonia Experimental	- .24	+ .07	- .13
Shock Control	- .20	- .35	- .29
Ammonia Control	+ .64*	- .41	- .44

* $p < .05$

Inspection of this portion of the table reveals that only one of 12 correlations was significant. In this case, high baseline blood-pressure levels were associated with large blood-pressure increases to CS onset.

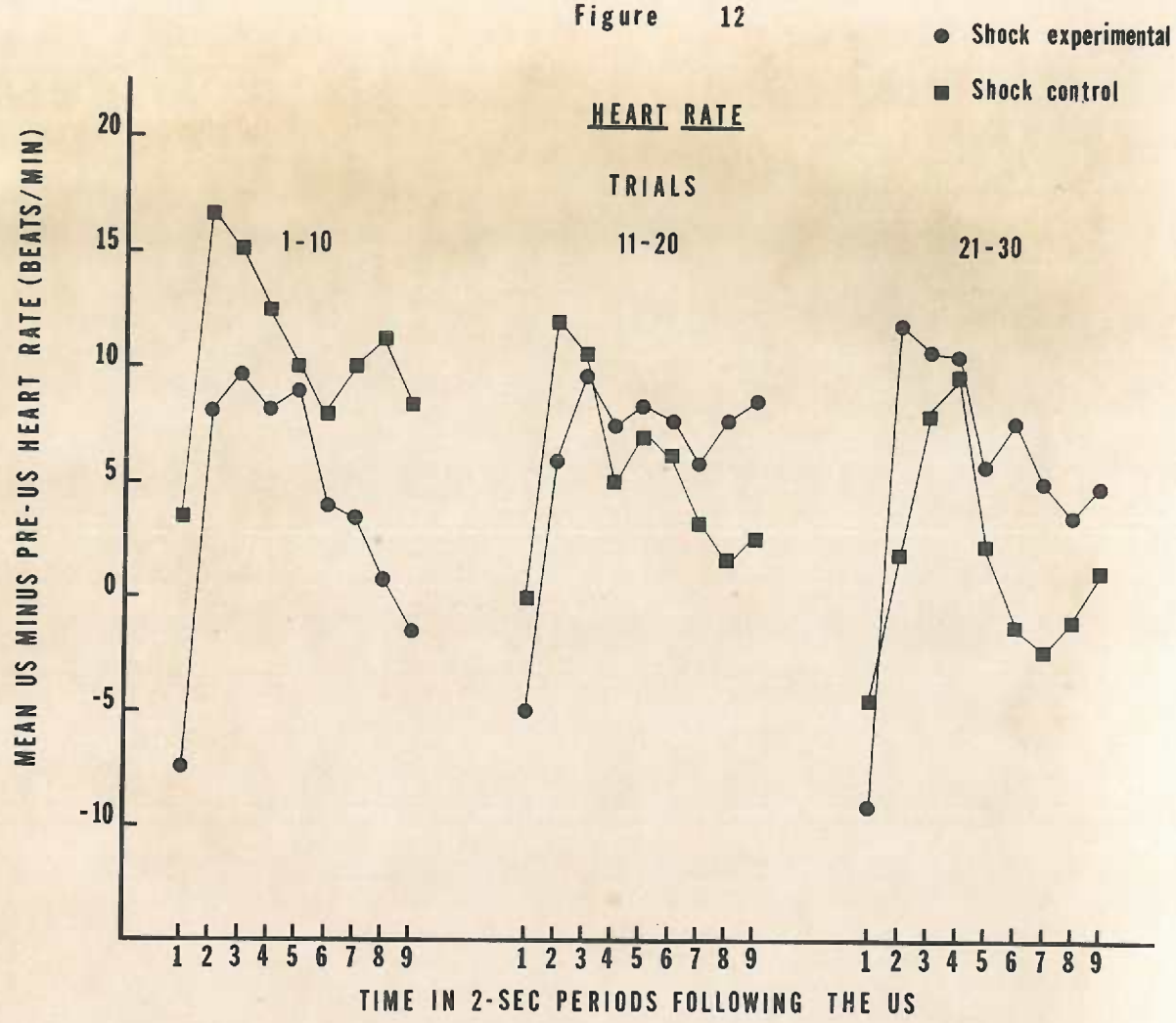
Analogous to the tests performed on the blood-pressure data, correlations between pre-CS heart rate and heart-rate responses during the three periods of the CS were carried out and included in the bottom portion of Table 3. This section of the table indicates that only one of 12 correlations was significant. This result meant that for the ammonia control group, low baseline heart rates were associated with large decreases in heart rate during the first period of the CS.

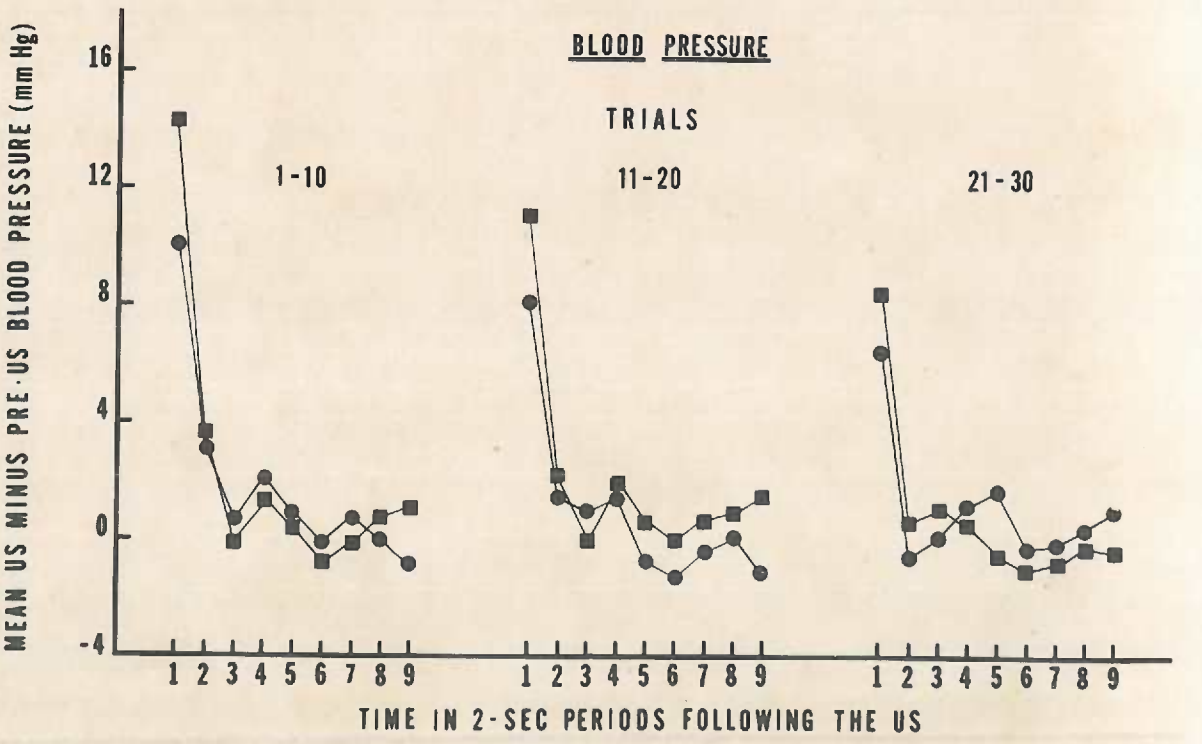
Unconditioned Responses

The unconditioned heart-rate responses of the experimental and control groups to electric shock were measured in nine 2-sec periods beginning 0.2 sec after the offset of the shock. For the experimental group, difference scores were formed by subtracting the 6-sec pre-CS period from each of the nine periods following the termination of the US (post-US periods). In the case of the control group, difference scores resulted from subtracting a 6-sec pre-US period from each of the post-US periods. The difference scores of both groups, averaged over three successive 10-trial blocks, are pictured on the top of Figure 12. The direction of the heart-rate responses of both groups were basically accelerative with maximum increases occurring approximately 4 to 6 sec after shock offset. During the first post-US period, there was evidence of cardiodecelerations in each trial block in the experimental group and in the final trial block in the control group. A significant counting periods effect, F (8, 176) = 14.32, $p < .001$, was provided by a 2 x 3 x 9 (experimental vs control x trial blocks x counting periods) analysis of variance revealing that the overall topography of the heart-rate reaction to shock was reliable. There also was a significant experimental vs control x counting periods interaction, F (8, 176) = 2.00, $p < .05$, demonstrating that the response topographies of the experimental and control groups were reliably different. Seperate t tests established that the cardiodeceleration in the experimental group during the first counting period was significantly different from zero ($p < .05$) in the first and third trial

Figure 12. Mean unconditioned heart rate and blood pressure responses of the experimental and control groups receiving the shock US in successive 2-sec counting periods averaged over three blocks of ten trials each. The heart rate and blood pressure reactions are shown at the top and at the bottom of the figure, respectively.

Figure 12


Shock experimental
Shock control
HEART RATE
TRIALS
1-10
11-20
21-30
MEAN US MINUS PRE-US HEART RATE (BEATS/MIN)
20
15
10
5
0
-5
-10
1 2 3 4 5 6 7 8 9
TIME IN 2-SEC PERIODS FOLLOWING THE US


BLOOD PRESSURE
TRIALS
1-10
11-20
21-30
MEAN US MINUS PRE-US BLOOD PRESSURE (mm Hg)
16
12
8
4
0
-4
1 2 3 4 5 6 7 8 9
TIME IN 2-SEC PERIODS FOLLOWING THE US

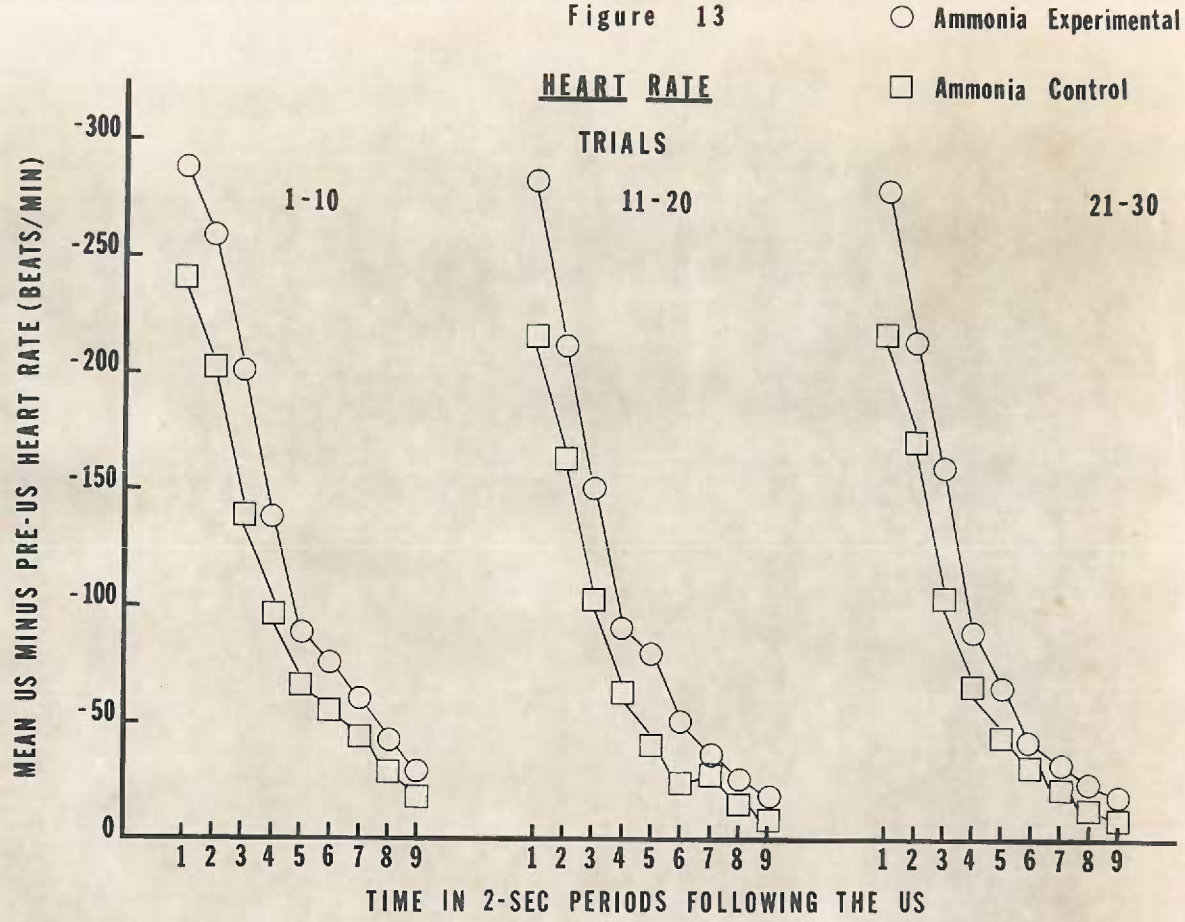
blocks but not in the second trial block. In the case of the control group, the first period cardiodeceleration at the end of the acquisition trials was not significantly different from zero.

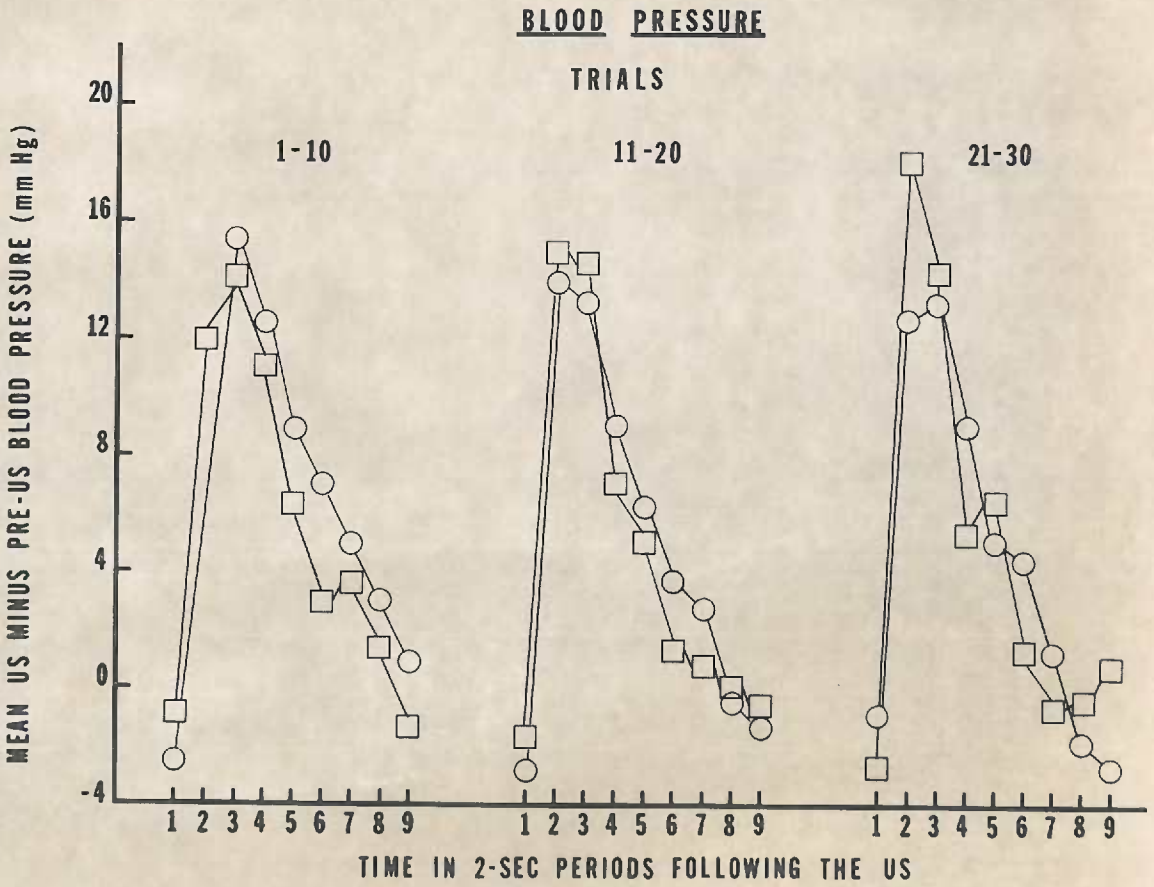
The unconditioned blood-pressure responses to the electric shock US were measured on each trial in nine successive 2-sec periods commencing 0.2 sec after the offset of the shock. Each counting period measurement was corrected for baselevel in a manner similar to that described earlier for heart rate. The bottom of Figure 12 depicts the blood-pressure difference scores for the experimental and control groups averaged over three successive blocks of 10 trials each. It is evident from this figure that the dominant response was an increase in blood pressure, and that the increase occurred within the first 2-sec period after shock. Subsequent to this initial change, blood pressure in both groups rapidly decreased toward baseline levels and then slightly increased again approximately 8 sec after shock. In general, the magnitude of this secondary, relatively long-latency increase as well as that of the primary, short-latency increase became smaller over the acquisition trials. In a 2 x 3 x 9 (experimental vs control x trial blocks x counting periods) analysis of variance, there was a significant counting periods effect, F (8, 176) = 46.77, $p < .001$, revealing that blood pressure changed reliably across the post-shock counting periods. There was also a significant trial blocks x counting periods interaction, F (16, 352) = 4.58, $p < .01$, indicating that the change in the topography of the response across trials was reliable.

The top section of Figure 13 depicts the mean unconditioned heart-rate responses of the experimental and control groups to the ammonia fumes US in nine consecutive 2-sec periods averaged over three blocks of 10 trials each. The reactions in each of the nine periods were corrected for baseline in a manner identical to that used for the shock US. The first counting period began at a point approximately coincident with the arrival of the ammonia gas in the animal's chamber. From an inspection of the figure, it is evident that both groups demonstrated a pronounced bradycardia to ammonia fumes inhalation. The magnitude of this bradycardia was maximal during the first 2-sec counting period. In general, the response topographies of each group were similar with the magnitudes of the cardiodecelerations decreasing to near baseline by the final counting period, or after 18 sec. In addition, the magnitudes of the heart-rate responses of both groups appeared to decrease slightly across trials. The only apparent difference between the experimental and control groups was the tendency for the magnitudes of the control group's responses to be smaller than those of the experimental group. In a 2 x 3 x 9 (experimental vs control x trial blocks x counting periods) analysis of variance performed on these data, there was a significant counting periods effect, F (8, 176) = 201.12, $p < .001$, demonstrating that the overall change in heart rate during the post-US periods was reliable. In addition, there was a significant counting periods x trial blocks interaction, F (16, 352) = 4.38, $p < .001$, indicating that the topography of the heart-rate response varied reliably across trial blocks.

Figure 13. Mean unconditioned heart rate and blood pressure responses of the experimental and control groups receiving the ammonia-fumes US in successive 2-sec counting periods averaged over three blocks of ten trials each. The heart rate and blood pressure reactions are shown at the top and at the bottom of the figure, respectively.

Figure 13


Ammonia Experimental
Ammonia Control
HEART RATE
TRIALS
1-10
11-20
21-30
MEAN US MINUS PRE-US HEART RATE (BEATS/MIN)
-300
-250
-200
-150
-100
-50
0
1 2 3 4 5 6 7 8 9
TIME IN 2-SEC PERIODS FOLLOWING THE US


BLOOD PRESSURE
TRIALS
1-10
11-20
21-30
MEAN US MINUS PRE-US BLOOD PRESSURE (mm Hg)
20
16
12
8
4
0
-4
1 2 3 4 5 6 7 8 9
TIME IN 2-SEC PERIODS FOLLOWING THE US

A significant trial blocks effect, F (2, 44)) = 23.02, $p < .001$, established that the overall decrease in the magnitude of the heart-rate responses across trials was reliable. With regard to group differences, there was a significant experimental vs control effect, F (1, 22) = 4.71, $p < .05$, revealing the overall mean of the experimental group was reliably greater than that of the control group. A significant experimental vs control x counting periods interaction, F (8, 176) = 3.37, $p < .005$, demonstrated that the topographies of the heart-rate response of the experimental and control groups were not the same. This interaction reflects the fact that there was a greater difference between the responses of the groups shortly after ammonia fumes inhalation than in later post-ammonia periods

The unconditioned blood-pressure responses to ammonia fumes in nine consecutive 2-sec periods corrected for baseline are presented in the bottom of Figure 13. From an inspection of this part of the figure, it can be seen that the responses to ammonia fumes had several components. Each group displayed a decrease in blood pressure within 2 sec of the arrival of the fumes in the test chamber. This was followed by a sharp rise in pressure which reached a peak level approximately 4 to 6 sec after the arrival of ammonia fumes. Blood pressure then decreased in succeeding measurement periods, and in general, went slightly below baseline by the end of the 18-sec recording segment. A 2 x 3 x 9 (experimental vs control x trial blocks x counting periods) analysis of variance yielded a significant counting periods effect, F (8, 176) = 45.19, $p < .001$, indicating that the overall change in

blood pressure across the counting periods was reliable. A significant trial blocks x counting periods interaction, F (2, 44) = 5.26, $p < .05$, was indicative of the fact that the topography of the blood-pressure response changed reliably over trial blocks. In addition, there was a significant experimental vs control x counting periods x trial blocks interaction, F (16, 352) = 2.85, $p < .001$, indicating that the topographies of the responses of the experimental and control groups were different during the different trial blocks. The latter interaction can be attributed to the fact that the overall magnitude of the initial depression and later elevation in blood pressure became smaller across trials in the case of the experimental groups, whereas for the control group both response components increased in size.

A re-examination of Figure 9 provides an example of unconditioned heart rate and blood-pressure responses to ammonia. The immediate effect of ammonia consisted of a period of cardiac arrest which lasted for approximately 2 sec. This was followed by a series of widely spaced beats that lasted approximately 5 sec. Subsequent to these beats, heart rate gradually increased and became more regular. The initial blood-pressure component of the cardiovascular reaction to ammonia was a precipitous fall in pressure which was syncronous and simultaneous with the cessation of heart activity. Coincident with the first two heart beats, blood pressure increased rapidly above baseline where it remained for approximately 8 sec. Although this record shows fluctuations in pressure during later post-US periods, the groups as a whole showed a gradual return of blood pressure toward baseline following the initial increase in pressure.

A series of Spearman rank-order correlation analyses was performed on the groups' unconditioned responses in the initial six 2-sec periods following the offset of the US. The data for these analyses were provided by difference scores averaged over the 30 acquisition trials. The correlation values for each group are listed in Table 4. From an inspection of this table, there is some evidence to indicate that heart rate and blood pressure tended to be correlated during the first post-US period with the correlations of all four groups being positive and two being significant. In the case of the shock experimental group, the significant correlation meant that large heart-rate decreases were associated with large increases in blood pressure. The significant correlation of the ammonia experimental group meant that large heart-rate decreases were associated with large blood-pressure decreases.

Table 4. Spearman rank-order correlations between unconditioned heart rate and blood pressure responses carried out on the data from the first six periods following the US averaged across the 30 acquisition trials. Significant correlations are denoted with an asterisk.

Group	Periods following the US					
	1	2	3	4	5	6
Shock Experimental	+ .61*	- .20	- .20	- .36	- .28	- .23
Ammonia Experimental	+ .65*	+ .20	- .09	- .01	+ .28	+ .55*
Shock Control	+ .41	- .19	- .08	+ .67*	+ .15	+ .03
Ammonia Control	+ .43	+ .29	- .01	- .19	- .03	+ .17

* $p < .05$

DISCUSSION

The principle findings of the present experiment were that: (a) the heart-rate orienting response to the CS during preconditioning trials was decelerative, while the blood-pressure orienting response was biphasic consisting of a reliable increase in pressure followed by a decrease in pressure. There was little evidence that the magnitudes of the heart-rate and blood-pressure reactions to the CS during preconditioning trials were correlated; (b) conditioned changes in heart rate and blood pressure were obtained using both electric shock and ammonia fumes as USs. The type of US employed did not influence the directions of the conditioned responses, even though the directions of the unconditioned responses were markedly different. Both USs led to the development of conditioned monophasic cardiodecelerations that reached their peak magnitude just prior to the delivery of the US. Blood-pressure responses of the experimental groups to the CS during acquisition training were biphasic consisting of a brief, short-latency increase to the onset of the CS followed by a more sustained, long-latency decrease that reached a peak toward the end of the CS. Of these two components, the decrease in pressure appeared to reflect the presence of conditioning. The magnitudes of the conditioned heart-rate and blood-pressure reactions were not reliably correlated with each other; (c) the dominant unconditioned heart-rate responses of the experimental and control groups to electric shock were accelerative. The experimental group also gave some evidence of brief cardiodecelerations immediately after

the termination of the shock. The unconditioned blood-pressure responses of the experimental and control groups to shock were increases in pressure. The two groups receiving the ammonia-fumes US showed monophasic heart-rate decelerations and biphasic blood-pressure changes consisting of a short-duration depressor response followed by a long-duration pressor response. For the experimental groups, the magnitudes of unconditioned heart rate and blood-pressure reactions were correlated immediately after the offset of the USs but not during later post-US periods.

Orienting Responses

In dogs, the initial presentation of an auditory stimulus evokes a constellation of responses involving skeletal-motor activity, such as head turning, pricking up the ears, and postural adjustments, as well as autonomic activity consisting of changes in heart rate, respiration, and galvanic skin potential. Pavlov (1927) termed this group of responses the investigatory or "What is it?" reflex. Other investigators have labelled such behaviors as orienting responses (e.g. Sokolov, 1963). More recently, the directions of the heart rate and blood-pressure components of the orienting response have been used as measures of cortical development in human infants (Clifton, 1974) and as indices of attention (Lacey and Lacey, 1974).

Pavlov (1927) emphasized the importance of the orienting response in his treatment of classical conditioning, reporting that conditioning may be retarded if the orienting response to the CS is too vigorous. Typically, in classical conditioning studies involving autonomic nervous system responses a number of trials with the CS

alone are given to habituate the orienting response before conditioning is started. Fitzgerald and Hoffman (1976) have recently shown that failure to give these preconditioning trials can have an adverse effect on subsequent heart-rate conditioning in rats.

Consistent with what has been found in prior studies involving rats (Fitzgerald and Hoffman, 1975; Martin, 1976; Stainbrook, 1975), the heart-rate orienting response in the present experiment was a cardiodeceleration. Also in the current study, the topography of the response was such that heart-rate deceleration was slightly greater at the end than at the beginning of the CS. The overall magnitude of the response did not appear to decrease across the preconditioning trials.

The blood-pressure response to the CS on the first half of the preconditioning trials was biphasic consisting of an initial increase in pressure followed by a decrease in pressure. The magnitude of the decrease component reached its peak toward the end of the CS. Over the last half of the trials, the topography of the blood-pressure orienting response changed with the overall magnitude of the decrease component of the response showing evidence of habituation. The increase component to CS onset appeared to remain intact across trials. This difference in the degree to which the two blood-pressure components changed over the pretest trials suggests that the decrease in pressure was not simply a reflexive adjustment to the increase in pressure elicited by the onset of the CS.

As will be discussed later, it is conceivable that the increase

in blood pressure was part of a more general startle reaction elicited by the sudden onset of the CS. Finding that at least part of the blood-pressure response showed evidence of habituation on the pretest trials whereas heart rate did not suggest that there was some degree of independence between the two responses on the pretest trials. Further evidence of independence was provided by the absence of reliable correlations between heart rate and blood pressure during this phase of the experiment.

Conditioned Responses

The conditioned heart-rate responses of both the shock and ammonia experimental groups took the form of a monophasic deceleration. The decelerative direction of the responses is an agreement with what restrained rats have shown in previous classical conditioned studies involving a wide range of stimulus parameters (Fitzgerald and Hoffman, 1976; Fitzgerald, Martin, and Hoffman, 1975; Holdstock and Schwartz-baum, 1965). The topographies of the responses in both groups were such that the magnitudes of the cardiodecelerations were maximal near the time that the US was scheduled to be presented. This response topography has been consistently observed in restrained rats (Fitz-gerald and Teyler, 1970; Fitzgerald, Martin, and O'Brien, 1973) as well as in pigeons (Cohen and Pitts, 1968) and suggests that Pavlovian inhibition of delay (Pavlov, 1927) may be present during cardiac conditioning. However, it should also be noted that the topography of the conditioned heart-rate responses of the experimental groups resembled at least to some extent, the topography of the orienting

heart-rate response elicited by the CS prior to conditioning. In both cases, heart-rate decelerations were larger at the end than at the beginning of the CS. The similarity of the two responses provides some support for the sensitization theory of cardiac conditioning outlined by Fitzgerald and Martin (1971). This point will be considered in more detail later in the discussion.

Finding that the type of US did not influence the direction or topography of the conditioned heart-rate reactions agrees with what Fitzgerald and Hoffman (1976) found for rats under similar circumstances. In their study as well as in the present investigation, the unconditioned response to electric shock was predominantly a cardioacceleration, while the unconditioned response to ammonia fumes was a cardiodeceleration. In spite of the opposing directions of these responses, the conditioned responses were uniformly decelerative. Failure of the heart-rate unconditioned response to influence the direction of the heart-rate conditioned response has also been reported for humans (Wilson, 1969). In addition, other investigators (Cohen and Obrist, 1975) have called attention to the fact that in a variety of learning situations in which classically conditioned changes in heart rate might be expected to occur, the direction of the conditioned and unconditioned responses have sometimes been divergent. The absence of a closer relationship between the conditioned and unconditioned heart-rate responses has made it difficult to apply traditional stimulus-substitution (Pavlov, 1927) or stimulus-response theories (Hilgard and Bower, 1975) to the results of some cardiac conditioning studies.

Even though the type of US did not influence the direction or topography of the conditioned heart-rate reaction, evidence was obtained suggesting that conditioning developed at a more rapid rate with the ammonia-fumes US than with the electric shock US. Statistical support for this possibility was provided by a reliable type of US x trial blocks interaction in the analysis of variance involving the two experimental groups. At the same time, however, the overall magnitudes of the heart-rate decelerations of the ammonia control group to the CS were considerably larger throughout acquisition training than those displayed by the shock control group. These differences between the control groups suggest that the ammonia-fumes US may have had a substantial sensitizing effect on heart rate. Such an effect could have contributed to the relatively rapid development of the conditioned heart-rate response of the ammonia experimental group.

The term sensitization has traditionally been defined within the context of classical conditioning as an augmentation of the original response to the CS in the absence of specific pairings of the CS and US (Hilgard and Marquis, 1940). The heart-rate responses of the ammonia control group during acquisition clearly fit this definition as they were in the same direction as the orienting responses on the pretest CS-alone trials, and they increased in size without the benefit of specific CS-US pairings. It is conceivable that the reason the ammonia US seemed to produce more sensitization than the shock US was because ammonia has more profound and widespread energizing

effects on the autonomic nervous system than does peripheral shock. Recent studies (e.g. McRitchie and White, 1974) have shown that in several species of animals inhalation of ammonia fumes produced marked increases in parasympathetic output. In the case of rats, unpublished results from our laboratory established that ammonia-induced cardiodecelerations were mediated primarily by increased vagal activity. The fact that the orienting and conditioned heart-rate responses of rats are also mediated principally by the vagus (Fitzgerald, Martin, and O'Brien, 1973) could increase the likelihood of finding substantial sensitization with an ammonia-fumes US.

During conditioning, the blood-pressure responses to the CS of the shock and ammonia experimental groups were biphasic consisting of relatively short-latency, small-magnitude increases in pressure followed immediately by more sustained, larger-magnitude decreases in pressure. On the other hand, the responses of the control group were basically monophasic increases, the latency, magnitude, and duration of which closely matched the increase component of the blood-pressure responses of the experimental groups. The similarity of the blood-pressure increases in the experimental and control groups suggests that this component of the blood-pressure response was not conditioned. Instead, it is possible that the blood-pressure increases may have been part of a more general startle response elicited by the sudden onset of the CS. Martin (1976) observed that restrained rats receiving differential classical conditioning training exhibited a brief burst of skeletal-motor acitivity to the onset of both CS+ and

CS-. These reactions were evident on the pretest CS-alone trials in his study, and they persisted in a slightly augmented form throughout conditioning. The fact that the blood-pressure increases in the current study followed a similar time course could indicate that they reflected cardiovascular adjustments to increased skeletal-motor activity.

The absence of blood-pressure decreases in the control groups to match those that occurred in the experimental groups suggests that the blood-pressure conditioned response was principally a decrease in pressure. This finding is in contrast to the results obtained by Pappas, DiCara, and Miller (1972) indicating that curarized rats showed conditioned increases in blood pressure. In the current study, the blood-pressure decreases of both experimental groups were maximal toward the end of the CS-US interval, just as in the case of the heart-rate conditioned responses. Thus, on the basis of the present experiment, the classically conditioned cardiac response of noncurarized restrained rats may be characterized as a decrease in heart rate coupled with a decrease in blood pressure with both responses reflecting the presence of Pavlovian inhibition of delay. This combined change indicates that the increased vagal activity, which was shown to be the primary mediator of conditioned heart-rate decelerations in rats (Fitzgerald, Martin, and O'Brien, 1973), was not triggered reflexively via the baroreceptors through an increase in arterial blood pressure.

Although pre-CS baseline blood pressure of the two control groups

was significantly elevated above that shown by the two experimental groups, this result cannot be used to account for the differences in the responses of the groups to the CS. That is, despite a higher baseline, the control groups still displayed pressor responses to CS onset comparable in magnitude to those of the experimental groups. In addition, even with the combination of higher baselines and pressor responses, the control groups failed to demonstrate depressor responses during the latter portions of the CS like those displayed by the experimental groups. Thus, elevated baseline blood-pressure levels did not appear either to inhibit increases or enhance decreases in blood pressure. This outcome is not congruent with the Law of Initial Values (Wilder, 1957). According to this law, high resting levels of autonomic activity increase the likelihood that a stimulus will elicit decreases in activity whereas low resting levels promote increases in activity to a stimulus. With reference to the current investigation, this law would predict that the control groups, because of an elevated baseline, should be more likely than the experimental groups to display decreases in blood pressure during the latter portions of the CS.

As mentioned earlier, Pappas et al. (1972) found that the conditioned blood-pressure responses of rats was an overall increase having two peaks during the 7-sec CS-US interval that they employed. The first increase occurred with a latency of approximately 2.0 sec after CS onset. Blood pressure then declined over the next 3 sec to near baseline. However, it did not go below the pre-CS baseline.

There was then a second increase in pressure which reached its peak during the final second of the CS-US interval. While the blood-pressure conditioned response that was obtained in the current study contained an increase component whose latency matched that of the first blood-pressure increase in the Pappas et al. (1972) experiment, no evidence of a second increase was observed. In fact, blood pressure decreased below the pre-CS level in the present study at approximately the same time that it increased in the Pappas et al. experiment.

One possible explanation for these divergent blood-pressure conditioned responses may be that in the Pappas et al. (1972) investigation, blood pressure was recorded from the lower abdominal aorta, while in the present study blood pressure was recorded from the middle caudal artery. Although blood-pressure responses could vary with respect to where they are monitored, this seems unlikely in the present case since the caudal artery in the rat lies near the abdominal aorta, and it would be expected that pressure changes would be comparable in the two vessels. Moreover, it has been shown that mean blood pressure as measured from the rat's caudal artery in the tail was not different from that measured from the common carotid artery in the neck (Fujita and Tedeschi, 1968).

A second, more likely, reason for the divergent outcomes of the two studies may be that in the Pappas et al. experiment the rats were curarized, whereas in the current study they were not. It has been reported that the drug, d-tubocurarine, that Pappas et al. used to paralyze the rats, may have central nervous system effects that

interfer with the development of conditioned cardiac responses. Brener, Eissenberg, and Middaugh (1974) stressed that respiratory variables such as peak-inspiratory pressure, chest diameter, respiratory rate, and the inspiration-to-expiration ratio were often not carefully controlled in studies involving curarization, and that these deficiencies may lead to unstable and/or elevated baseline heart-rate levels that could interfer with heart-rate conditioning.

Additional evidence suggests that d-tubocurarine or some other aspect of the curarization procedure may be capable of blocking or at least diminishing vagal output to the heart (Hahn, 1974). These latter findings are of particular relevance to the present discussion as an absence of vagal output could account for the failure of Pappas et al. to obtain conditioned heart-rate responses in their animals since such responses are known to be mediated primarily by increased vagal activity (Fitzgerald, Martin, and O'Brien, 1973). Other investigators have also reported diffficulty in producing classically conditioned heart-rate responses in curarized rats (Eissenberg, 1973; Hahn and Slaughter, 1970). For example, Ray and Brener (1973) reported that curarization blocked not only performance of classically conditioned heart-rate responses in rats but also the subsequent establishment of such responses.

In addition to its effects on heart rate, it is also possible that by interferring with normal vagal functioning, the curarization procedure employed in the Pappas et al.(1972) experiment could have prevented blood pressure from decreasing to the CS. Conceivably, the conditioned blood-pressure and heart-rate decreases that were

found in the current investigation were both mediated by increased vagal output. That vagal stimulation can elicit concurrent decreases in both blood pressure and heart rate has been demonstrated in monkeys (Randall, Kaye, Randall, Brady and Martin, 1976), in cats (Howard, Gaebelein, Galosy, and Obrist, 1975), and in rabbits (Allen, 1928, 1929a, 1929b). Other studies have shown that a vagally mediated decrease in ventricular contractility may lead to a decrease in blood pressure in dogs (DeGeest, Levy, Zieske, and Lipman, 1965), and in cats (McWilliam, 1888). Similarly, recent findings reported by Lin (1974) suggest that increased vagal activity could mediate a decrease in blood pressure in rats by decreasing the force of cardiac contractions. An alternative explanation, which places relatively less importance on the vagus, is that the conditioned blood-pressure decreases observed in the present study may have been triggered by a generalized loss of peripheral sympathetic tone. On the basis of this view, the CS may have acquired the capacity to generate both sympathetic and parasympathetic activity with the former being reflected in blood-pressure changes and the latter in heart-rate changes.

Several outcomes of the present study indicate that conditioned changes in heart rate and blood pressure may have been relatively independent of each other. First, the magnitudes of the conditioned heart-rate reactions were not systematically related to the magnitudes of the conditioned blood-pressure responses during any part of the CS-US intervals. Second, contrary to what was demonstrated for heart rate, type of US did not appear to influence the rate at which the blood-

pressure response became conditioned. As was discussed earlier, ammonia fumes appeared to augment the development of conditioned heart rate but not blood pressure. Furthermore, the ammonia control group showed heart-rate responses to the CS that were substantially larger than those shown by the shock control group. A comparable difference between the control groups was not found for blood pressure. While results such as these point to a certain degree of independence between heart rate and blood pressure, they do not necessarily rule out the possibility that the two responses shared common effector control from the vagus.

In agreement with what has been found in studies using humans (e.g. DeLeon, 1972), and rabbits (e.g. Powell and Kazis, 1976), the magnitude of the blood-pressure changes to the CS shown by the experimental groups during conditioning were relatively small. The group means for the increase and decrease components of the responses on the terminal conditioning trials were approximately 2-3 mm Hg. In some studies in which dogs (e.g. Antal and Gantt, 1970) or monkeys (Klose et al., 1975) were used as subjects, the blood-pressure conditioned responses were reported to be in the range of 7-12 mm Hg. While it is true that the overall magnitudes of conditioned blood-pressure reactions might be expected to vary with the type of species being investigated, it is also possible that the different measurement procedures that have been employed could have contributed to differences in response magnitudes. In some experiments, both systolic and diastolic pressures were measured on a beat-by-beat

this hypothesis, the conditioned response is an altered version of the orienting response, and therefore, it should be more similar to the orienting response than to the unconditioned response. Support for the sensitization hypothesis has been derived from results showing that the directions of the orienting and conditioned responses were the same (Fitzgerald and Hoffman, 1976; Girden, 1942; Klose et al., 1975; Newton and Perez-Cruet, 1967; Obrist, Wood, and Perez-Reyes, 1965) and from findings revealing that, at least in rats, the orienting and conditioned responses were both mediated by increased vagal output (Fitzgerald, Martin, and O'Brien, 1973). As would be predicted by the sensitization hypothesis, the orienting and conditioned heart-rate responses in the present study were similar to each other, in terms of both direction and topography. The most obvious effect of the conditioning procedure was in terms of the overall increase in the magnitudes of heart-rate decelerations that developed to the CS.

The blood-pressure results also provide support for the sensitization hypothesis. Thus, the topography of the conditioned blood-pressure reactions exhibited by the experimental groups were highly similar to the orienting responses elicited by the CS at the beginning of the pretest CS-alone trials. In both cases, the reactions were biphasic consisting of an increase followed by a decrease in pressure. On the other hand, the control groups displayed blood-pressure responses to the CS on the unpaired acquisition trials that clearly matched the habituated responses occurring to the CS at the

end of the pretest trials. Thus, the conditioning paradigm seemed to rebuild or reinstate the depressor response in the experimental groups after that response had been habituated by the preconditioning trials.

Prokasy (1965) proposed a response-shaping hypothesis to account for the development of conditioned responses in classical conditioning situations. He suggested that subjects gradually learn to execute certain responses in close temporal proximity to the US because such responses were more reinforcing than those performed earlier in the CS period. Finding that the heart-rate and blood-pressure conditioned responses were maximal near the time that the US was scheduled to occur is consistent with this viewpoint.

In a related hypothesis, Schneiderman (1973) argued that the conditioned cardiac response may have adaptive significance in that it may help prepare the organism to cope with the effects of the US. As cited by Hilgard and Marquis (1940), this view has had a long history in classical conditioning. However, it appears to have limited usefulness in the context of the present experiment since the blood-pressure and heart-rate conditioned responses that developed to the ammonia US were similar to the conditioned responses generated by the shock US. This was true even though the unconditioned responses to the two USs were markedly different. If it is argued that the conditioned decreases in heart rate and blood pressure helped the rats cope with the unconditioned increases in both responses elicited by the shock US then it difficult to understand how the same condi-

tioned decreases could have helped the rats cope with the profound unconditioned decreases in both responses elicited by the ammonia US.

As mentioned earlier, the stimulus substitution theory of conditioning requires that the conditioned response resemble, to some degree, the unconditioned response. At one level, this notion gains little support for the results of the present investigation since conditioned heart-rate responses were uniformly decelerative while the unconditioned reactions were either decelerative or primarily accelerative. Moreover, the conditioned blood-pressure reaction was primarily a decrease, whereas the unconditioned response was either a biphasic (decrease-increase) change or a monophasic increase. The fact that the direction of the blood-pressure conditioned response was not affected by the direction of the unconditioned response is contrary to what has been observed in humans and dogs (e.g. DeLeon, 1972; Whitehead et al., 1976). A comparison of separate studies involving these two kinds of subjects suggests the possibility that conditioned blood pressure changes may match unconditioned changes.

Some support for the stimulus substitution explanation of heart-rate conditioning in rats may be gained by considering the neural systems that are principally involved in the occurrence of the conditioned and unconditioned responses. It has been noted that in rats, increased vagal activity may help mediate unconditioned cardiodecelerations to electric shock (Fitzgerald, 1976) and to ammonia fumes (Fitzgerald, unpublished observations). Furthermore, direct vagal stimulation was shown as an effective US for the development of conditioned decreases

in heart rate (Fitzgerald, Martin, and Hoffman, 1975) and to facilitate heart-rate conditioning when combined with other USs (Fitzgerald and Hoffman, 1976). Finally, increased vagal output is known to be primarily involved in the control of conditioned cardiodecelerations in rats (Fitzgerald, Martin, and O'Brien, 1973). Taken together, these results suggest, in keeping with the stimulus substitution notion, that conditioned and unconditioned heart-rate responses in rats may share efferent vagal control.

Unconditioned Responses

Unconditioned heart-rate responses to shock of the experimental group were biphasic consisting of a short-latency, small-magnitude cardiodeceleration followed by a long-latency, large-magnitude cardioacceleration. In the case of the control group, heart-rate responses to shock initially included a relatively small-magnitude acceleration followed by a larger, more sustained acceleration during succeeding periods. Over the course of the shock trials, the magnitude of the initial acceleration decreased and tended to become a deceleration. Previous studies have also shown that under certain conditions, rats display heart-rate decelerations to shock (Fitzgerald and Teyler, 1970; Stern and Ward, 1961; Teyler, 1971). Stainbrook (1976) found that rats injected with a high dose of ethanol exhibited short-latency cardiodecelerations to shock that persisted for 20 shock trials. Recently, Fitzgerald (1976) demonstrated that cardiodecelerations of restrained rats to shock were blocked by atropine suggesting that the responses were vagally mediated.

It will be recalled that unconditioned heart-rate responses in the current investigation were difference scores computed by subtracting the number of heart beats during the 6-sec pre-CS period from the number of beats during successive s-sec periods following the offset of the shock. In order to determine if the cardiodecelerations of the experimental groups in the current study actually represented decreases in heart rate below the heart-rate levels immediately prior to shock, an alternative method of measuring the unconditioned responses was employed. This method utilized heart rate during the last 2 sec of the CS as the baseline. With this method the direction of the heart-rate response in the first counting period after shock changed from a slight deceleration to a slight acceleration. This indicates that the direction of the unconditioned heart-rate reaction to shock can vary according to the baseline against which it is compared. On the other hand, Fitzgerald and Teyler (1970) found that heart-rate responses to shock were decelerative when heart-rate activity during the CS or during the pre-CS period was used as the baseline for computing the difference scores.

With respect to the accelerative portion of the heart-rate reaction to shock, there is some evidence to suggest that such increases may involve both sympathetic and parasympathetic activity. In curarized rats (Pappas, et al., 1972) and in cats (Howard, Smith, Mueller, and Breese, 1974), cardiodecelerations to shock were attenuated by chemical sympathectomy. In addition, Fitzgerald (1976) provided data indicating that shock-induced cardioaccelerations in

rats may involve decreased vagal activity in that the magnitude of the reactions were reduced by atropine-blocked of parasympathetic activity.

The unconditioned increases in blood pressure that occurred to shock in the present study are consistent with what has been reported for cats (Hein, 1969), dogs (Katcher, Solomon, Overmier, and Rescorla, 1969), monkeys (Randall, Daye, Randall, Brady, and Martin, 1976), and rabbits (Yehle, Dauth, and Schneiderman, 1967). Pappas et al. (1972) also found that blood pressure increased to shock in rats and that this increase substantially diminished by sympathectomy; thus indicating major sympathetic involvement in the reaction. In the present study, the magnitude of the blood-pressure increase immediately after shock offset tended to be correlated with the magnitude of the heart-rate change. This finding suggests, in contrast to the heart-rate conditioned response, that the blood-pressure baroreceptor mechanism may have contributed at least in part to early post-shock changes in heart rate. It will be recalled that Powell et al. (1972) also found that unconditioned cardiodecelerations in rabbits may be reflexively produced at least in part by increased blood pressure.

A biphasic unconditioned blood-pressure response was elicited by the ammonia-fumes US along with a profound decrease in heart rate. The early component of the blood-pressure response was a short-duration decrease in pressure which was followed by a more sustained increase in pressure lasting up to 15 sec. An examination of the rats' polygraph recordings revealed that the decrease in pressure

occurred when there was a complete absence of heart beats. In some rats this condition persisted for up to 2 sec, especially to the first few ammonia presentations. Subsequent to this period of inactivity, both heart rate and blood pressure started to increase with blood pressure increasing in a stepwise fashion with successive beats exceeding its pre-ammonia baselevel pressure prior to the time at which heart rate recovered to its baselevel. McWilliam (1888) noted that following vagal stimulation blood pressure initially decreased then increased in a similar stepwise fashion. He referred to this phenomenon as resembling Bowditch's Treppe or staircase (Mountcastle, 1974).

A number of experiments have been reported dealing with the possible physiological mechansims underlying ammonia-induced changes in the cardiovascular system (Allen, 1928; McRitchie and White, 1974; Visser et al., 1956). In general, these investigations have shown that respiratory modifications were among the first reactions to occur to ammonia fumes. An early investigation by Kratschmer (1870) indicated that in cats and rabbits chemical irritation of the nasal mucosa by ammonia led to closure of the larynx, bronchoconstriction, apnea, and occasionally expiratory arrest. Cromer, Young, and Ivy (1933) reported that ammonia vapor also produced apnea in dogs and that this response was accompanied by decreases in heart rate and blood pressure. Similar decreases in heart rate in response to ammonia inhalation were also noted in rabbits (Allen, 1928, 1929a, b; Kosupkin and Olmsted, 1943; Visser, de Geus, and Heuting, 1956). Both increases and decreases in blood pressure to ammonia have been

reported for cats and rabbits (Banister, Fegler, and Hebb, 1949; Allen, 1928; McRitchie and White, 1974). In apparent contrast to these findings, Callanan, Dixon, Widdicome, and Wise (1974) reported that ammonia fumes led to increases in both heart rate and blood pressure in geese. They attributed these opposing outcomes to different anatomical arrangements of the lungs and air passages of birds as opposed to other mammals.

Several investigators have attempted to delineate the neural structures that are involved in the mediation of cardiovascular reactions to ammonia insufflation (Allen, 1928; Kratschmer, 1870). In a comprehensive study, McRitchie and White (1974) provided evidence on the relative contributions of trigeminal, olfactory, carotid sinus and aortic nerves in the occurrence of heart rate, blood pressure and respiratory changes to ammonia fumes in rabbits. They reported that the major determinant of heart-rate decreases and blood-pressure increases was provided by the trigeminal. The authors suggested that trigeminal input from lung-inflation receptors following apnea and direct stimulation of nasal receptors that project to brain centers controlling heart rate and blood pressure such as the bulbar reticular formation. Although it is clear that the ammonia-fumes US in the current study elicited patterns for activity in response systems quite unlike those activated by the shock US, there was nevertheless a remarkable similarity in the conditioned reactions generated by the two USs.

SUMMARY AND CONCLUSIONS

The purpose of the present investigation was to provide information on the direction, magnitude, and topography of classicall conditioned changes in arterial blood pressure and heart rate in restrained rats. Blood pressure was recorded from the cannulated middle caudal artery in the rat's tail. A 2 x 2 factorial design was employed in which one dimension was the conditioning procedure (paired conditioning trials with the CS and US vs a pseudoconditioning control arrangement involving explicitly unpaired presentations of the CS and US). The other dimension was the type of US employed (a .5-sec 1.2-ma electric shock vs inhalation of ammonia fumes). Forty-eight rats were randomly assigned to the four groups making up this design. All animals received a 15-min period of adaptation to the conditioning chamber followed by 10 preconditioning trials with the 2.9 kHz tone that served as the CS. Animals in the conditioning groups then received 30 paired conditioning trials using a delayed conditioning procedure in which the CS-US interval was 6 sec. Animals in the two control groups were given 30 unpaired presentations of the CS and US.

The principle findings were that the type of US that was used as the reinforcement did not influence the direction or topography of either the conditioned heart-rate responses or the conditioned blood-pressure reactions. The directions of the conditioned heart-rate responses were decelerative to both USs. The conditioned blood-pressure reactions were biphasic and consisted of a short-latency increase in

pressure followed by a more sustained decrease in pressure. The topography of both responses suggested the presence of Pavlovian inhibition of delay in that maximum cardiodecelerations and blood-pressure decreases occurred just prior to the delivery of the US. Moveover, the topographies of both conditioned responses were similar to those that were present for the orienting responses on the preconditioning CS-alone trials. Little evidence was found to suggest that the heart-rate and blood-pressure changes that occurred to the CS either during pretest or during conditioning, were dependent upon each other. The unconditioned heart-rate response to electric shock was mainly accelerative, whereas to ammonia fumes, heart rate decelerated. Blood-pressure changes elicited by shock and by ammonia were monophasic increases and biphasic decreases followed by increases, respectively.

It was suggested that the results tended to support a sensitization view of cardiac conditioning that emphasizes the similarity of orienting and conditioned responses rather than traditional stimulus-response or stimulus-stimulus theories of conditioning that stress the importance of unconditioned responses. The occurrence of the conditioned decrease in blood pressure was discussed in terms of direct vagal activity and in terms of peripheral vasodilation.

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Study	CS	US	Heart rate conditioned response	Blood pressure conditioned response	Heart rate unconditioned response	Blood pressure unconditioned response
Humans						
Beier (1940)	buzzer	exercise	variable between Ss	variable within Ss	not reported	not reported
De Leon (1972)	light	shock	not reported	increase	not reported	not reported
Obrist et al (1972)	light	shock	biphasic	increase	not reported	not reported
Whitehead et al (1976)	tone	body-tilt	not reported	decrease	not reported	decrease
Monkeys						
Brady et al. (1969)	click	shock	variable within Ss	increase	not reported	not reported
Klose et al. (1975)	tone	shock	increase	increase	not reported	not reported
Ewes						
Naitoh (1970)	click	shock	increase	increase	increase	increase
Dogs						
Girden (1942)	light	shock	not reported	increase	not reported	increase
Kozenko (1952)	tone	peripheral vagus	not reported	decrease	not reported	decrease
		carotid sinus	not reported	decrease	not reported	decrease
Kit (1958)	tone	phrenic nerve	not reported	decrease	not reported	decrease

Study	CS	US	Heart rate conditioned response	Blood pressure conditioned response	Heart rate unconditioned response	Blood pressure unconditioned response
Dogs (continued)						
Dykman et al. (1960)	tone	shock	increase	increase	increase	increase
Mack et al. (1961)	tone	shock	increase	increase	increase	increase
Dykman et al. (1965)	tone	shock	increase	increase	increase	increase
Newton et al. (1967)	tone	shock	variable between Ss	variable between Ss	increase	variable within Ss
Antal (1968)	sound	treadmill	increase	increase	increase	increase
Katcher et al. (1969)	tone	shock	increase	increase	increase	increase
Andrus et al. (1970)	tone	proximal vagus	no conditioning	no conditioning	variable within Ss	variable within Ss
Antal et al. (1970)	whistle	shock	increase	decrease	increase	decrease
Kakigi (1971)	tone	shock	increase	increase	not reported	not reported
Bergamaschi et al. (1973)	tone	loud noise	increase	increase	increase	increase
Rabbits						
Yehle et al. (1967)	tone	shock	decrease	increase	decrease	biphasic
Schneiderman et al. (1969)	tone	shock	decrease	no conditioning	decrease	increase

Study	CS	US	Heart rate conditioned response	Blood pressure conditioned response	Heart rate unconditioned response	Blood pressure unconditioned response
Rabbits (continued)						
VanDercar et al. (1970)	ICS*	ICS	decrease	increase (11% of trials)	decrease	increase
Powell et al. (1972)	none used	ICS	not reported	not reported	decrease	increase
Metcalf et al. (1973)	ICS	ICS	decrease	increase	decrease	increase
Sampson et al. (1974)	tone	ICS	decrease	no conditioning	decrease	increase
Powell et al. (1976)	tone	shock	variable within Ss	variable within Ss	not reported	not reported
Cats						
Hein (1969)	tone	shock	decrease	increase	decrease	increase
Rats						
Pappas et al. (1972)	tone-light	shock	no conditioning	increase	increase	increase
Williams et al.(1972)	none used	footshock	not reported	not reported	not reported	decrease
		footshock with 6-OHDA	not reported	not reported	not reported	increase

* intracranial stimulation