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THE EFFECT OF EQUIPMENT ALARMS ON THE HEART RATE AND BLOOD FLOW OF HEALTHY ADULTS IN A SIMULATED ICU ENVIRONMENT

THE UNIVERSITY OF ARIZONA M.S. 1985

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THE EFFECT OF EQUIPMENT ALARMS ON THE HEART RATE AND BLOOD FLOW OF HEALTHY ADULTS IN A SIMULATED ICU ENVIRONMENT

by

Diane Coleman Shelton

A Thesis Submitted to the Faculty of the

COLLEGE OF NURSING

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

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This thesis has been approved on the date shown below:

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Assistant Professor of Nursing

December 21, 1984
Date

DEDICATION

To Willis H. P. Shelton

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ABSTRACT

The purpose of this study was to test the effect of alarm noise, commonly heard in an intensive care unit (ICU), on the heart rate and blood flow of healthy adults in a simulated ICU environment. Eighteen subjects spent one eight hour night each in a laboratory and their responses to alarm noise were measured by polygraph recording.

The study used an experimental design with subjects as their own control. It was predicted that each of the five sounds would cause an alteration in heart rate and a decrease in blood flow. All hypotheses were supported.

The results demonstrated the reactions to noise of healthy individuals. Research needs to be conducted on patients in ICUs to determine whether their responses are the same. Nurses should consider the possibility that patients may be experiencing stress from the frequent alarms occurring in the environment and take steps to reduce the noise or physically alter the environment.

CHAPTER I

INTRODUCTION

"Quiet, Hospital Zone." This sign can be seen outside many hospitals. Yet, studies show that hospitals are not quiet places, for wherever people are there are human sounds, both vocal and those caused by activity. Hospitals have become increasingly mechanized. Equipment is used throughout the hospital due to the need for accuracy, time-management, continuous monitoring, and provision of patient services. Sounds of operation and alarms are associated with much of this equipment. These sounds contribute to the noise that patients are exposed to day and night.

Delineation of Problem

Noise is a problem both to patients and in hospitals. This section defines sound and noise and documents that noise is, indeed, a problem with which nurses need be concerned.

Sound is measured on a decibel (dB) scale, which is a logarithmic scale. Zero dB is a reference point and is not equal to the absence of sound, but rather to the softest sound which humans can hear, known as the auditory threshold. As a sound increases in intensity or loudness, it is measured with increasing decibels. An increase from 0 to 10 decibels is equal to a tenfold increase in sound and an increase from 0 to 20 decibels is equal to a one hundredfold increase in sound (Baron 1970). A sound level meter is used to measure decibels of sound.

The decibel scale measures sound at all frequencies or pitches, even those sounds above or below the range of human hearing. The human ear is not as sensitive to low frequency sounds as it is to higher pitched sounds. To adjust for this, a corrected decibel scale, the "A" decibel (dB(A)) is used (Baron 1970). Some frequently heard sounds and their dB(A) values are: rustling leaves, 20 dB(A); a room in a quiet dwelling at midnight, 32 dB(A); conversational speech, 60 dB(A); heavy city traffic, 92 dB(A); a home lawn mower, 98 dB(A); a jet airline at 500 feet overhead, 115 dB(A) (Baron 1970).

Noise is defined by the Environmental Protection Agency (1972) as "any sound which is undesirable because it interferes with speech and hearing, or is intense enough to damage hearing, or is otherwise annoying" (p. G-6). Noise, then, can be any sound, if it is judged by an individual to be undesirable or annoying.

Hospitals care for people who are ill. These individuals need observation and care, not only during daylight hours, but also throughout the night. To ill individuals, the moans, groans, coughs and cries of another patient might be distressing. The footsteps of the staff members' shoes upon the linoleum in the hallway could be annoying, and the conversation of staff members may be disturbing to persons who are in pain or trying to sleep.

In a study by Whitfield (1975), questionnaires were distributed to patients and night staff on a large open hospital ward. Patients reported that the most distressing noises were those made by other patients, nurses talking to other patients in the ward,

and equipment noises such as beds creaking, phones ringing, doors banging and glass urinals being set down.

In a study conducted by Ogilvie (1980), the researcher measured the decibel level on the dB(A) scale of common hospital noises at night. Coughing, doors closing, telephones ringing and glass urinal noises were found to be the loudest sounds, measuring as high as 60-70 dB(A).

The intensive care unit (ICU) is an area where care is delivered to individuals whose illness requires more nursing time than can be provided by staffing ratios on a general unit, or where individuals who require the use of equipment needing constant observation are admitted. All of this equipment generates operating sounds as well as various alarms to alert the operator, usually the nurse, that the machine is finished, is malfunctioning, or requires adjustment.

One group of researchers (Redding, Hargest and Minsky 1977) measured the noise level in an ICU by placing a sound level meter in the center of four ICU cubicles, thus the sound they measured did not represent what any one patient heard. The background noise level ranged from 71-77 dB(A). The hospital cafeteria at noon measured 75 dB(A). Individual machines and treatments were measured at more or less than this average sound.

Bentley, Murphy and Dudley (1977) also measured mean noise levels in an ICU. They found that the mean noise level was 72 dB from 0800 to 1600, 65 dB from 1600 to 2400, and 62 dB from 2400 to 0600. These mean noise levels were frequently interrupted by loud

noises which were defined by the authors as greater than 70 dB. The main causes of the noise in the ICU were equipment and conversations among the staff.

These studies have shown that intensive care units contain noise as defined by the Environmental Protection Agency. Since the ICU is organized to care for the critically ill, the effect of this noise on patient welfare is important.

The effect of sounds on physiologic functioning is known intellectually by most people. Everyone has been startled at some time by someone speaking suddenly in a quiet room, the ringing of an alarm clock, or a telephone call during the night. After the initial startle, it often takes a few seconds to stop feeling nervous and jumpy. The response is probably due to activation of the sympathetic nervous system; therefore one would expect an alteration in pulse rate, vasoconstriction, and other physiologic changes.

Studies involving loud continuous noise have linked that noise to hypertension (Andrén, Lindstedt, Bjorkman, Borg and Hansson 1982). Detailed studies have been done involving the effect of a single loud noise on individuals using a gunshot (Landis and Hunt 1939) or a sonic boom (Griefahn 1975a). Response to this magnitude of stimulus and the effects of chronic noise have been well studied and include a change in heart rate, elevation of blood pressure and a drop in skin resistance.

The physiologic response to noise of the same intensity as equipment alarms and bells has not been studied adequately. The relationship between alarm noise, and heart rate and blood flow need

to be established in healthy subjects before ICU patients may be studied. Once this relationship is established, a second study can be done to determine whether ill patients respond in the same, a greater, or a lesser manner.

Significance of the Study

Noise in intensive care units is a significant problem to study because the effects of this noise have the potential to be harmful. Noise is a problem which also has the potential to be modified.

In some settings, the sympathetic response may have injurious results. Individuals who are experiencing an illness caused by inadequate perfusion of oxygen to their myocardium, may poorly tolerate the increased need for oxygen that occurs when the individual is stressed by noise.

Sound in an ICU is potentially modifiable. Different brands of equipment have different sounds. Alarms could be insulated by maintenance departments to muffle the sounds. Manufacturers of equipment could be asked to modify their equipment alarms. Telephones could be switched from a loud ring to a less startling sound. Finally, if alarm noise does indeed alter heart rates and cause vasoconstriction, then the physical arrangement within an ICU can be altered. The patient with an acute myocardial infarction may need to be isolated from, or physically removed from the individual on a ventilator. Those who construct future ICUs could use this

information. Nurses can utilize this information and can physically separate patients from sound sources whenever possible.

Purpose of Study

The purpose of this study was to determine what effect five selected alarms and bells commonly heard in an ICU have on the heart rate and blood flow of resting healthy subjects during the nighttime hours. This study proposed to answer the following questions.

In a resting healthy individual, is there a significant change in heart rate and a decrease in blood flow due to

1. The sound of a ventilator pressure alarm?
2. The sound of a ventilator disconnect alarm?
3. The sound of an infusion pump alarm?
4. The sound of a telephone ring?
5. The sound of a cardiac monitor alarm?

It was hypothesized that there will be a change in heart rate and a decrease in blood flow to each of the five sounds. These responses are more clearly delineated in Chapter Two.

Summary

Noise in hospitals results from activities of patients and equipment. Noise is not only loud sounds, but undesirable or annoying sounds. Noise can be measured on a sound level meter using decibels. A decibel scale that has been corrected for human hearing is the decibel "A" scale. The noise level in intensive care units has been measured at 62-75 dB(A) with individual equipment often exceeding this level.

Loud noise, continuous or intermittent, has been linked to hypertension and stimulation of the sympathetic nervous system. In individuals with limited cardiac reserve, this sympathetic stimulation has the potential to be harmful. This study sought to determine whether equipment alarms commonly found in an ICU caused a heart rate response and a blood flow decrease in normal subjects. Five sounds were tested. The implications of this study are that it is possible to modify noise and that noise may need to be modified for patient welfare.

CHAPTER II

CONCEPTUAL FRAMEWORK

This chapter presents the conceptual framework for this study and Figure 1 represents the conceptual model to be used. This chapter defines and discusses the concepts and relationships found in the model. The first two concepts to be discussed are noise and the stress response. An overview of these two areas are presented and then the relationship between them are discussed. Next, intensive care unit (ICU) noise is presented, followed by a discussion of the five selected alarm noises. Finally, the specific studies using heart rate response and blood flow as their measurements are presented as well as the use of the R-R interval and finger volume pulse.

Noise

Noise, by definition, is "any sound which is undesirable because it interferes with speech and hearing, or is intense enough to damage hearing, or is otherwise annoying" (EPA 1972, p. G-6). Conversational speech is 60 decibels (A) (dB(A)). Sound at 60 dB(A) would cause one to raise his voice or cause difficulties in hearing; and therefore sound as relatively quiet as 60 dB(A) can be labeled noise. Also, sound judged to be annoying, which is subjective and certainly affected by many external factors, is noise.

Noise has the potential to be harmful. Chronic exposure to industrial noise at 95 dB(A) has been strongly implicated as contributing to hypertension and hearing loss (Sandén and Axelsson 1981).

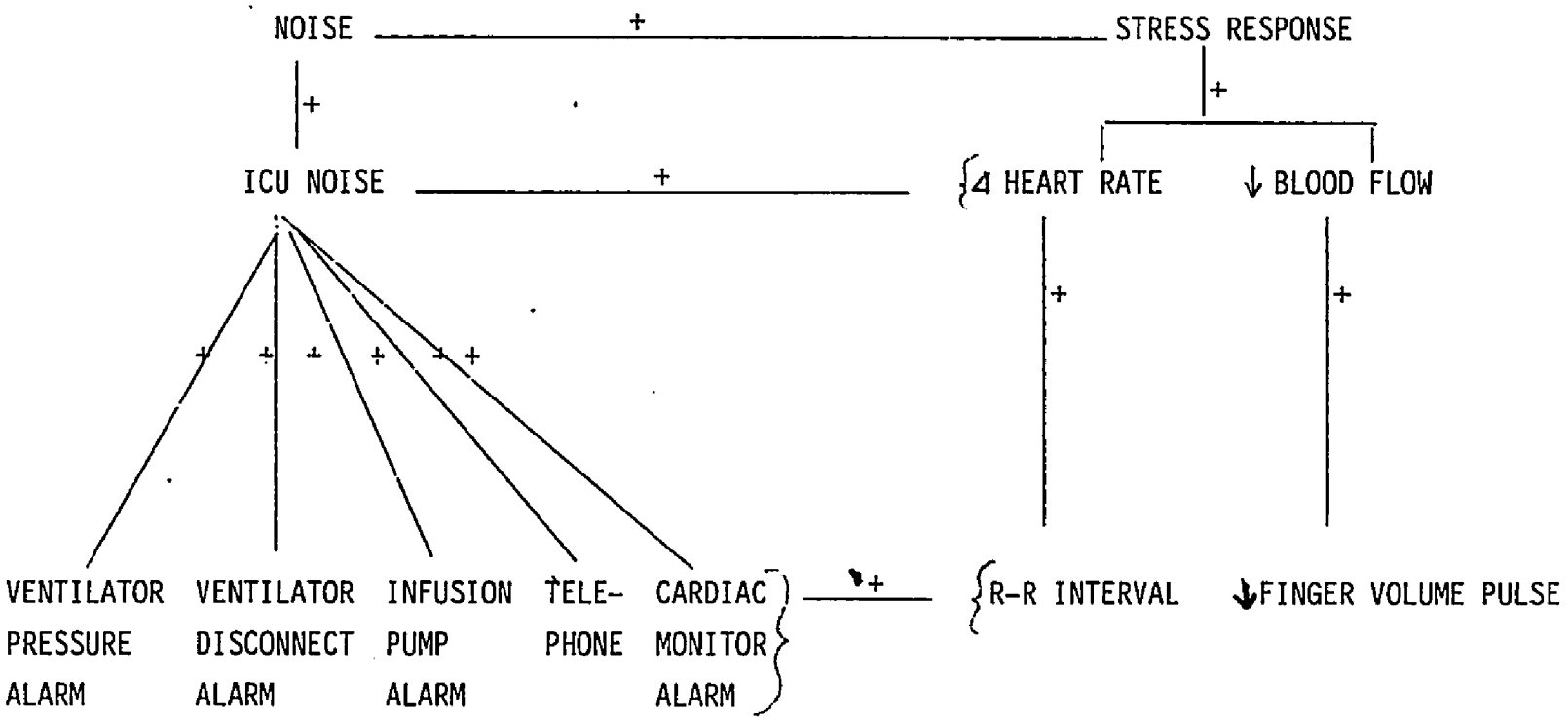


Figure 1. Conceptual Model

Twenty minutes of exposure to industrial noise at 95 dB(A) caused a significant ($p<0.001$) increase in diastolic blood pressure in 15 healthy subjects (Andrén et al. 1982).

Sleep can be interrupted or disturbed by noise. Thiessen (1970) stated that a noise 40-45 dB(A) has a 10 to 20 percent chance of causing an individual to awaken or change his stage of sleep. A 50 dB(A) noise has a 50 percent chance of awakening the subject or altering his sleep stage. With a 70 dB(A) noise the most probable reaction will be awakening, the second most likely is a change in sleep stage. Griefahn and Muzet (1978) found that sleeping individuals habituated to the noise, causing less disturbances in their sleep, but that their heart rate did not habituate. In a similar study, the finger pulse did not habituate to the sound (Griefahn 1975b).

Gädeke, Döring, Keller and Vogel (1969) examined the effect of noise on sleeping infants. More than one third of the infants exposed to 65 dB noise for 12 minutes awoke. Between one half and two thirds of the infants awoke to three minutes of noise at 70-75 dB. When 75 dB noise was applied, the researchers consistently found sleep disturbances or awakening. Those infants who awoke did so with the startle reflex. The startle reflex, present in infants until the age of four or five months occurs when, in response to a sudden stimulus, the baby stiffens his body, draws up his legs, and throws his arms up and out; the arms then return to an embrace position.

The sound itself and its familiarity and meaning to the subject is also of import. Oswald, Taylor and Treisman (1960) used

sleep deprived subjects and asked them to awaken when they heard their name and one other specific name. The subjects slept while a tape was played which continuously called 56 names. Subjects aroused significantly ($p<0.001$) more often to their name than to the control name.

Wilson and Zung (1966) studied a group of subjects to determine whether they had the ability to discriminate and awaken to the desired sounds more frequently than to control sounds. Subjects were told that they would be paid extra if they awoke to the designated sounds. More than 90 percent of the subjects awoke to the specified sounds, which was significantly ($p<0.05$) higher than the response rate for the alternate sounds.

Noise, or undesirable sound, has been linked with hypertension and sleep disturbances. Although subjects gradually develop the ability to sleep through the noise, they still respond physiologically. Individuals seem to have the ability to discriminate between important and unimportant sounds in their sleep. Various intensities and durations of noise have been used to stimulate an autonomic response. The studies done in this area are reported later in this chapter.

Stress Response

The second concept discussed in this chapter is the stress response. This section describes the response, and the research done in this area.

Humans and animals have the ability to react to their environment. The autonomic nervous system provides a means to speed up

or slow down various body systems according to an individual's needs. The sympathetic nervous system prepares an individual to fight or run away when confronted with emotion-producing stimuli. Fear and rage are the emotions most commonly associated with this system. In a study by Levi (1967), subjects responded both to a violent film and a humorous film by increasing their urinary excretion of adrenalin. This led Levi to conclude that any strong emotion in humans will lead to some response by the sympathetic nervous system.

This sympathetic response has been labeled differently by many authors (Bartoshuk 1962; Atherley 1967; Griefahn and Muzet 1978; Cantrell 1979; Hilton 1979). Words like alert, alarm, defense, arousal and stress have been used to describe the phenomenon. For the purpose of this study, the autonomic response is called the stress response.

The stress response is not an all or none reaction. Davis, Buchwald and Frankman (1955) found that the cardiovascular response was proportional to the intensity of the stimulus when they used sounds 70 to 120 dB.

The stress response affects nearly all systems of the body. The blood vessels constrict, and the diastolic blood pressure rises. Skin pales, pupils dilate, and eyes close. The subject winces, holds his breath, and his muscles, both voluntary and involuntary, tense. Gastric secretion decreases while adrenalin is released into the blood stream causing neuromuscular tension, nervousness, irritability, and anxiety. These changes are regulated by the autonomic nervous system (Rosen 1970).

The stress response, labeled as such for this study, is responsible for multisystem changes in the body. These changes are regulated by the autonomic nervous system. The body can react to any strong emotion. The response is proportional to the stimulus.

Relationship Between Noise and Stress Response

The concepts of noise and the stress response have been discussed in previous paragraphs. This section establishes a relationship between the two concepts.

Noise, at varying intensities and durations, has been used by researchers as a stimulus to evoke a stress response. Atherley (1967) noted the relationship between noise and a physiologic response, but doubted whether noise itself caused the physiologic changes or whether the individual's interpretation of the significance of the noise created the response.

Landis and Hunt (1939) thought that a sudden loud sound was the most reliable stimulus to evoke a galvanic skin response which they suggest using to measure the activity of the sympathetic nervous system. However, these researchers used a gunshot and primarily dealt with the behavioral responses to noise.

Different noises were used for different studies, but the responses evoked were similar. Sonic booms were used as stimuli while pulse rates were monitored (Griefahn 1975a). The sonic booms caused a biphasic heart rate response which is discussed in a later section of this chapter. In infants exposed to repeated acoustic

clicks lasting one second at 85 dB, there was a significant ($p<.001$) increase in the pulse rate (Bartoshuk 1962).

Sackler (in Atherley 1967) used 90 to 120 dB noise as an intermittent stimulus to rats and found changes in testicular and seminal vesicle structure, adrenal gland weight, and pituitary mass. These changes were not found in rats belonging to the control group which received no noise stimulus.

Davis et al. (1955) measured the human response to auditory stimuli at 70 to 120 dB. Galvanic skin response, pressure pulse, breathing amplitude, breathing rate, heart rate, systolic blood pressure, finger volume response, volume pulse and skeletal muscle tension were measured before the stimulus was applied and for 10 seconds after the stimulus. All of these variables altered due to the noise stimuli. The heart rate and pressure pulse had a biphasic response. The galvanic skin response, finger volume response and volume pulse decreased. The breathing amplitude and rate, the systolic blood pressure and the muscle tension increased. Davis et al. (1955) did find that the magnitude of the response was related to the intensity of the noise.

The specific response by the subjects in the study of Davis et al. (1955) was a type I cardiovascular response characterized by two phases. The first phase consists of

> cardiac acceleration, vasoconstriction, smaller pressure pulse and probably increased diastolic pressure. The second phase is characterized by continued vasoconstriction (with some recovery), stronger pressure pulse, subnormal heart rate, and probably increased systolic as well as diastolic pressure (Davis et al. 1955, p. 10).

Noise has been used as a stimulus in well controlled studies and has been shown to have effects on the sympathetic nervous system. Alteration of heart rate and decreased volume pulse were among the physiologic findings caused by noise.

Intensive Care Unit (ICU) Noise

Noise is sound that is undesirable, annoying or interferes with speech and hearing. Noise which interferes with sleep must also be considered undesirable. Noise levels greater than 50 dB have been found to affect sleep in 25 percent of adults (Anagnostakis, Petmezakis, Messaritakis and Matsaniotis 1980). Sound that causes an individual to startle and to have physiologic changes must be considered noise.

Hospitals are associated with many kinds of noises. There is patient noise, staff noise and equipment noise. In intensive care units (ICU) there is likely to be increased staff noise since staff/patient ratios are higher. There is also a higher density of equipment. All coronary-care patients and most intensive-care patients are attached to a cardiac monitor. Many medications administered in ICUs need to be delivered with such precision that infusion pumps are routinely used. Patients whose respiratory status is such that they require the use of a ventilator are usually admitted to an ICU.

Redding et al. (1977) measured the background noise level in an area between four ICU cubicles and found the noise level ranged from 71 to 77 dB(A). Falk and Woods (1973) found a 24 hour average

sound level of 60.1 dB(A) in one room and 55.8 dB(A) in another room in an ICU. There were intermittent noises which were louder than the background noise.

Noise at 55 to 77 dB(A) level certainly has the potential to interfere with speech and hearing. It may also disturb the sleep of the individual. Sound in ICUs, found to be within these levels, is noise.

Operational Measures of Intensive Care Unit Noise

Several researchers have reported the levels or frequency of various equipment noises and alarms. The findings of these researchers for the five selected noises to be used in this study are presented below.

Ventilator Disconnect and Pressure Alarms

Redding et al. (1977) measured a Bennett MA_1 ventilator pressure alarm at 76 dB(A) 10 feet from the equipment. The disconnect alarm was 83 dB(A) at a distance of 10 feet and 92 dB(A) at the patient's head. Falk and Woods (1973) measured a Bennett MA_1 alarm, though the type of alarm, either disconnect or pressure, was not specified, at 66 dB(A). Grassl-Herwehe (1979) also did not separate the types of alarms, but found that the ventilators in the pediatric ICU rang 108 times in 40 hours.

Infusion Pump Alarm

Neither Falk and Woods (1973) nor Redding et al. (1977) measured the intensity of an infusion pump alarm. The frequency

of the alarm in the pediatric ICU was 41 times in 40 hours (Grassl-Herwehe 1979).

Telephone

Using a hospital setting, the loudness of the telephone was measured on two different types of wards (Ogilvie 1980). The open ward registered 62 to 64 dB for a telephone ring. The unit with enclosed cubicles for patients had a level of 53 dB for the telephone. In an ICU, 10 feet from the phone, the noise of the telephone measured 67 dB(A) (Redding et al. 1977). In a pediatric ICU, the phone rang 86 times in 40 hours (Grassl-Herwehe 1979).

Cardiac Monitor Alarm

A cardiac monitor disconnect alarm was measured at 80 dB(A), 10 feet from the source and the monitor rate alarm was measured at 71 dB(A) at the patient's head (Redding et al. 1977). In the study by Grassl-Herwehe (1979) in a pediatric ICU, the cardiac monitor was found to alarm 158 times in a 40 hour period.

Each of the above five sounds has been shown to occur at least once an hour in an ICU setting. The loudness of each sound is of a magnitude such that each must be considered noise.

Heart Rate and Blood Flow

The two measurements of the stress response used in this study were heart rate and blood flow. Neither of these indicators requires an invasive procedure for use and therefore the indicators were suitable for this study using normal subjects. These two

indicators have been used alone or together in a number of studies which measured the stress response to noise.

Neonates responded with an average increase of 11.3 heart beats per minute when exposed to bursts of acoustic clicks lasting one second at 85 dB (Bartoshuk 1962). This was the only study found where the heart rate response increased to this degree.

The heart rate response obtained in other studies was a biphasic response of acceleration, then deceleration. Davis et al. (1955) used noises of 70, 90, 120 dB. They found an increased heart rate that reached its maximum rate at the fifth beat post-stimulus, then a slowing to a rate significantly ($p<0.05$) below the baseline pulse which reached a minimum at the tenth post-stimulus beat. Simultaneous measuring of the volume pulse from the finger showed a marked decrease in blood flow starting 2.5 seconds post-stimulus. This represents vasoconstriction to the area and was thought by the researchers to correspond with an increasing blood pressure. The decrease in pulse rate is believed by Davis et al. (1955) to be due to a compensatory response to the blood pressure elevation. These results reflect the Type I cardiovascular response. The response to the different intensities of noise produced the same biphasic curve of the pulse but the magnitude varied with the intensity of the stimulus.

Hord, Lubin and Johnson (1966) used a three-second auditory stimulus which was 30 dB above threshold on sleeping subjects. Their results showed the same biphasic response. The peak acceleration occurred on the fourth post-stimulus beat and the peak deceleration

occurred on the tenth post-stimulus beat. They used sleeping subjects because the heart rate response habituates in awake subjects.

Griefahn (1975a) also found this biphasic response in pulse rate when exposing subjects to sonic booms during sleep. She found a maximal increase in the fourth second post-stimulus followed by a decrease below the baseline pulse rate.

The two measurements of the stress response used in this study were heart rate and blood flow. Each has been used and shown effective in several studies measuring the physiologic response to noise.

Operational Measures of Heart Rate and Blood Flow

Many different physiologic effects have been measured and used to evaluate a subject's response to a stimulus. This study used the heart rate and blood flow to determine subjects' response. The R-R interval and volume pulse, two noninvasive tests, are operational measures for heart rate and blood flow.

R-R Interval

The R-R interval is defined as the distance from the beginning of one QRS interval on the electrocardiogram (ECG) paper to the beginning of the next QRS interval. The QRS interval represents ventricular depolarization. Davis et al. (1955) used the R-R interval to evaluate heart rate. As the R-R interval decreases, the heart rate increases. They measured the R-R intervals in two 2.5 second

periods before the stimulus and in each of four 2.5 second periods after the stimulus.

Volume Pulse

Volume pulse is defined as the difference between maximum and minimum excursion of the pulse wave. The volume pulse measures the resistance to distension by the vessel walls and is measured by a plethysmograph (Davis et al. 1955). Davis et al. used the left index finger and compared four 2.5 second post-stimulus intervals to the two pre-stimulus intervals.

Summary

The definition of noise allows for very individual and subjective interpretation. Noise is known to cause hypertension in laboratory experiments and causes awakening or sleep stage interruption in many subjects. Loud noise has also been used to evoke a stress response in a number of studies.

Evidence has been presented to support the fact that many different types of noise stimuli are capable of causing the stress response. The stress response causes a whole range of physiologic responses, among which are change in pulse rate, either an increase or a biphasic response, and a decrease in blood flow. These two indicators can be measured noninvasively.

Noise occurring in intensive care units, although not as loud as many of the stimuli used in the various studies, is probably capable of producing an altered heart rate and blood flow. This

study endeavored to determine whether five selected noises commonly heard in ICUs caused an alteration in pulse rate and decrease in blood flow in healthy subjects.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine how an individuals' heart rate and blood flow responds to five sounds commonly heard in intensive care units (ICUs). This chapter describes the methodology used in this study. Before describing the data collection procedure, the design, sample, setting, treatment stimuli and measurement of response are addressed. Finally the method of data analysis, the potential sources of bias and the pilot study are discussed.

Design

This study utilized an experimental design with each subject serving as his own control. Subjects' heart rates were measured before and after each stimulus to determine whether a change had occurred.

Sample and Setting

Twenty healthy volunteers were recruited. The subjects were not health professionals nor individuals familiar with hospital equipment. The subjects did not have known heart disease or hearing problems and were not taking medications which might alter their heart rate response. All subjects were adults aged 18 or older. All subjects were familiar with the telephone ring, but unfamiliar with the four equipment alarms. Subjects were not restricted in regards to smoking habits or diet.

In summary, the criteria for selection were:

1. Age 18 years or older
2. Taking no medications affecting heart rate
3. Not a health professional
4. Currently healthy
5. No known heart problems
6. No known hearing problems

A controlled laboratory setting was utilized for this study. A bed was placed in a quiet room in a building that was only open in the daytime; hence, traffic at night when the study was conducted was minimal. Subjects were asked to spend an entire night (eight hours) in the laboratory. The investigator and equipment were in an adjacent room, separated by a wall with a two way mirror. Speakers present in the room provided the noise stimuli. Bathrooms were present in the area of the laboratory.

College students living in a dormitory who were interested in participating, attended a group meeting where questions were answered. Students were told they would receive 20 dollars for participating in the study. Prior to inclusion in this study, each subject read a subject disclaimer form (Appendix A) and each subject signed up for a date to participate at that time. The proposal for this study was submitted to and approved by the University of Arizona Human Subjects Committee (Appendix B).

Treatment Stimulus

This study centers around noise stimuli. To ensure accurate reproduction of the volume of noise found in intensive care units (ICU) at night, sound level meter readings were done. This section reports the levels and recording procedures for the alarms and background noise.

Background Noise

Readings from the Simpson sound level meter model 886 using the "A" scale, were done in three different ICUs during the late evening hours. In rooms where a ventilator was present, the average sound level was 59 dB(A). To reproduce this level of sound, an empty hospital room was utilized. The room was in an area of the hospital not currently in use, so that footstep and voice sounds were eliminated. The background noises included the air conditioning, the Bennett MA_1 ventilator operating sounds, and the suction machine. The noise provided by this equipment was recorded on a Sony TC 353D reel to reel tape recorder using Maxell Ultradynamic UD50-7 tape. The tape speed was seven and a half feet per second. The tape was spliced into a loop so that the same level of background noise would play for eight hours continuously without a pause.

Alarm Noise

The five alarm or bell noises were recorded from the reel to reel tape onto Scotch Heavy Duty VHS tape using a Panasonic NV8170 VHS random access recorder. Each sound was recorded in an isolated area to avoid picking up additional background sound.

In order to accurately measure the subjects' response, each alarm sound was rung a single time. This was to prevent the measurement of response to each succeeding sound. When an infusion pump alarms, it beeps once every two seconds until someone stops it which may be 15 seconds or more. In this study it only beeped once.

The ventilator pressure alarm was at the intensity that a patient would hear if the ventilator was used for a patient in an adjacent bed, which was five feet at one hospital. This alarm was measured on a Bennett MA_1 ventilator and was found to be 76 dB(A). This machine normally alarms singly. One alarm sound was played per stimulus.

The ventilator disconnect alarm was recorded at the intensity that a patient would hear if the ventilator was used for a patient in an adjacent bed, which was five feet at one institution. This alarm was measured on a Bennett MA_1 ventilator and was found to be 76 dB(A). This alarm normally rings with a rapid beeping continuously until it is cancelled. In this study it was stopped after three rapid beeps.

An infusion pump alarm was recorded at the intensity that a patient would hear if the pump was at the side of the bed. The alarm of the IMED Volumetric 927 infusion pump was measured and was found to be 68 dB(A). A single beep was used as a stimulus.

A telephone was recorded at the intensity that a patient would hear if the phone rang at the nurses' station. This distance to

different beds was measured and averaged 25 feet. The intensity of the ring averaged 62 dB(A). A single telephone ring was used as a stimulus.

The cardiac monitor alarm was recorded at the intensity that a patient would hear if the monitor was at the head of the bed. In an actual ICU, using the sound level meter, the intensity of a Hewlett-Packard 78534A cardiac monitor alarm averaged 70 dB(A) at the patient's head. The cardiac monitor alarm rang once per stimulus.

Sound Level Assurance

During the study, the tape recorder was in the room adjacent to the laboratory room. Speakers were placed in two areas of the laboratory room. JBL speakers, model L26 were used. The sound was amplified with a Crown D150 amplifier. The amplifier has two channels, one for the tape recording of the ambient noise and one for the alarm noises. The advantage of this amplifier is that when it senses no signal on the tape, it shuts off sound production to prevent tape hiss.

Each night, prior to the subjects' arrival, the decibel level at the head of the bed was checked for accuracy and the volume on the amplifier was adjusted to assure a 59 dB(A) level for the background sound. Each of five alarm noises were also checked to assure the desired volume in the same manner.

Measurement of Response

Each subject was connected to the polygraph machine and four channels were measured intermittently through the night. This

section describes the equipment used and how the subjects were attached.

Polygraph Machine

Four channels of the Grass Model 7D multichannel polygraph were used. Two channels were used for the heart rate and plethysmograph functions described below. Eye movements (EOG) and skeletal muscle tension (EMG) were monitored to allow the investigator to determine, from the adjacent room, whether the subject's eyes were closed and if he was relaxed.

Three electrodes were placed in a horizontal line across the forehead to measure the muscular tension of the frontalis muscle. One electrode was placed just lateral to the right eye and one electrode was placed on the right ear lobe (Figure 2).

Cardiac Monitor (ECG)

Each subject's heart rate was monitored only when the polygraph was running. The cardiac monitor was attached to one channel of the polygraph. Readouts were run for five seconds before the stimulus and for 10 seconds after the stimulus.

Subjects had three electrodes placed on their chest and were monitored in a lead 2. The negative electrode was placed on the right subclavian area, the positive electrode was placed on the left abdomen and the ground electrode was placed on the left subclavian area (Figure 3).

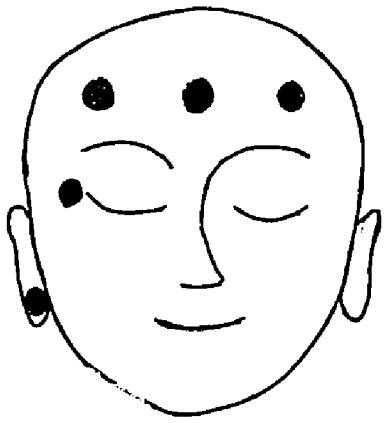


Figure 2. Placement of Facial Electrodes

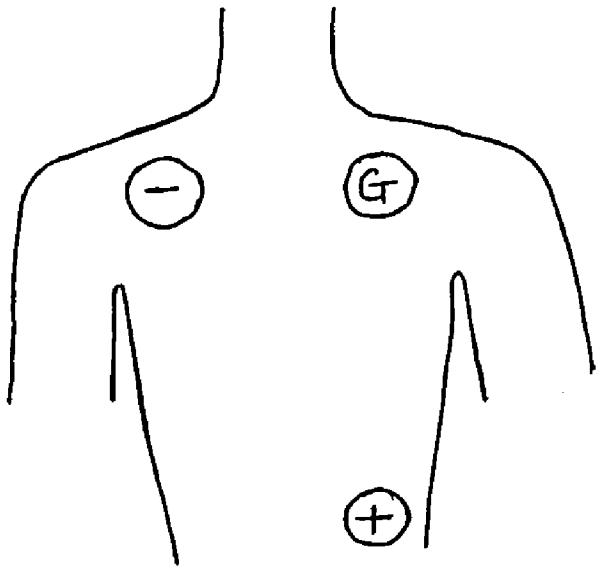


Figure 3. Placement of Chest Electrodes

Plethysmograph

The volume pulse was measured by a plethysmograph. A transducer was applied to the right index finger and then was connected to one channel of the polygraph.

Specifications of the Polygraph

The sensitivity of the instrument indicates its ability to detect changes in the variable being measured. The preamplifier measuring the ECG has a sensitivity range of 0.1 to 50 millivolt/centimeter (mv/cm). Nine different sensitivities can be achieved. Each is accurate at $\pm$ 2 percent. These sensitivities refer to R wave height which was unimportant for the purpose of this study. The R-R interval measures rate. The preamplifiers measuring the other three functions have a sensitivity range of 0.1 to 400 mv/cm. Each has a 12 step control, accurate at each step to $\pm$ 2 percent.

The sensitivity setting chosen determined the amplitude of the volume pulse wave form. The same sensitivity was maintained throughout a pre- and post-stimulus period. The wave form height was not measured in any unit but rather in the number of 1 millimeter (mm) boxes on the polygraph paper and a comparison of the pre-stimulus and post-stimulus heights was done. This ratio is constant independent of the units or accuracy of those units. When heights of the finger volume pulse wave form are presented in Chapter Four, the height is reported in boxes which are the 1 millimeter boxes of the polygraph paper. Whenever the term "boxes" is used in the remainder of this paper, it refers to the 1 mm boxes on the polygraph paper.

Calibration is a procedure in which the machine is adjusted so that indicated values equal actual values. All four pre-amplifiers will calibrate with an accuracy of ± 2 percent from a 1 mv (ECG) or 2 mv (other three) signal.

Stability describes the machine's ability to maintain its calibration over time. The pre-amplifier measuring the ECG has a baseline which will vary not more than a half millimeter from random sources or voltage variations. The pre-amplifiers measuring the other three variables have a baseline shift of not more than three microvolts per hour and less than one microvolt from any voltage variation. Information given on sensitivity, calibration, and stability was extracted from the manual by Grass Instruments (1974).

Data Collection Procedure

Each subject had a choice of having the study run from 10 pm to 6 am or 11 pm to 7 am depending on what suited their normal sleep habits. The night hours were chosen because studies have shown that the heart rate response to repeated noise does not habituate during sleep (Griefahn and Muzet 1978). Also, it has been shown that the difference between peak and background noise is important: the greater the difference, the greater the disturbance (Griefahn and Muzet 1978). During the night hours there is less background noise, which produces a greater difference between the peak and background noise levels.

After arrival at the laboratory, each subject was attached to the polygraph machine with three chest electrodes, five facial

electrodes and the finger transducer, as discussed in the measurement of response section. Each subject was then instructed to rest or sleep. The subjects could, but were not required, to sleep. Sleep was not required in this study because it has been shown that individuals sleep poorly in ICUs. Hilton (1976) studied the sleep patterns of 10 intensive care unit patients for 48 hours. She found that none of the patients completed even one full cycle of sleep. Also, the equipment used in this study did not provide enough information for the investigator to determine whether the subject was asleep.

Subjects in this study did not spend a preparatory night in the laboratory, as is customary in sleep studies. It was not necessary for this study, since ICU patients who spend their first night in the hospital do not have a night to adjust to their environment before being exposed to noise stress.

Once the subject had his electrodes attached and was in bed the background noise recording was started. The background noise played for one hour before specific alarm sounds were played.

During the next six hours, the subjects heard six alarm sounds per hour. Each hour the cardiac monitor alarmed twice and each other noise alarmed once. These frequencies are based on Grassl-Herwehe's study (1979) but were adjusted slightly for the following reasons. Her study took place in a pediatric ICU and spanned all hours of the day and night. She found that the cardiac monitor alarmed 158 times in 40 hours or almost four times per hour. Assuming that children are more active than adults and that there is more movement during daytime than nighttime, there would be an increased number of alarms

due to artifact and disconnection in a pediatric population than there would be in adults at night. Therefore in this study, the cardiac monitor alarm rang twice an hour.

Grassl-Herwehe (1979) found that the telephone rang 86 times in 40 hours or roughly twice an hour. Her study included daytime and nighttime hours. Considering that many ancillary personnel work only in the daytime, it is expected that there would be many more phone calls in the daytime than in the nighttime. Therefore, in this study the telephone rang only once an hour.

The other three alarms adhered to Grassl-Herwehe's (1979) findings. She found that the infusion pumps alarmed 41 times in 40 hours or once an hour. She found that the ventilator alarmed 108 times in 40 hours or roughly two and a half times per hour. In this study, each ventilator alarm, both disconnect and pressure, rang once an hour.

The tape recordings of these six sounds were randomly ordered and randomly spaced over each of six hourly administrations. Six sequences were randomly selected for each subject (Appendix C). Five seconds prior to each alarm noise and for 10 seconds afterwards, the polygraph was run, providing a recording of each subject's responses.

In the final hour of the study, the subject heard the background ICU sounds but received no alarm stimuli. The subject was then awakened, disconnected and allowed to leave. If a subject needed to use the bathroom or needed anything during the night, they knocked on the communicating door and the investigator unhooked the subject.

The random sequence was stopped and restarted 15 or 20 minutes later. In this case, the subject would hear less than a full hour of background noise alone in the morning. The data collection process is summarized in Figure 4.

Data Analysis

The heart rate and finger volume pulse were divided into 2.5 second intervals for analysis purposes. The two 2.5 second intervals just prior to the stimulus were measured for a control and the four 2.5 second intervals after each stimulus were measured for response. For the heart rate, the R-R interval measurement was used. Each complete R-R interval within the 2.5 second interval was measured and then averaged to give an average R-R interval length for that 2.5 second interval.

The measurement of the volume pulse was also divided into the same six segments. The difference between maximum and minimum excursion for each 2.5 second interval was determined and each value was calculated in relation to the pre-stimulus value of 100 percent.

The difference over the four post-stimulus intervals and the differences over the six hours of alarm administrations were examined using a repeated measures analysis of covariance, using the average of the two pre-stimulus values as the covariate. Then, each of the four post-stimulus intervals was compared for significant changes against the mean of the two pre-stimulus intervals. This was done for both heart rate and blood flow. A paired t-test with a significance level of 0.01 was also done for each post-stimulus value paired

1. Electrodes attached, connected to polygraph machine.

2. Subject went to bed.

3. Background ICU noise started. Hours 1-8.

4. Alarm noise six times an hour, random order, random intervals. Hours 2-7.

5. Polygraphic recording five seconds before stimulus and 10 seconds afterward.

6. End of hour 8, subject disconnected.

Figure 4. Data Collection Process

with the pre-stimulus mean. It was recognized that using four sets of paired t-tests alters the significance level. The alpha level was set low (0.01) to account for this.

Potential Sources of Bias

Two potential sources of bias were identified. Subjects were informed regarding the nature of the study. The subject could not have prepared for upcoming sounds due to the random schedule. However, subjects could have, perhaps, caused an exaggerated response if they were attempting to improve the data collected.

The investigator could have biased the data analysis by measuring only one R-R interval within the 2.5 second interval rather than averaging all the R-R intervals within that time. This could have allowed her to exaggerate or minimize responses. This was protected against by averaging all R-R intervals within the 2.5 second period. Also intrarater and interrater retesting was done to assure consistency. One randomly selected alarm stimuli from each subject was checked by a second rater for interrater reliability. The investigator rechecked two randomly selected alarms from each of the 18 subjects to assure intrarater reliability.

Pilot Study

A pilot study with one subject was conducted prior to the start of the actual data collection. The purpose of this pilot was to give the investigator practice setting off the alarm noises according to the protocol and to determine whether it is possible to set

the alarm noises off after one minute intervals. Many of the random sequences have one minute intervals between alarms.

It was determined that it was possible to set off the alarms at the appropriate intervals. It was also found that the blood flow response was not complete at 10 seconds. Also, when the polygraph was first turned on, the subject was noted to occasionally be already vasoconstricted. For these reasons, it was decided to run the polygraph for 15 seconds before the alarm to allow the investigator to watch the blood flow pattern before the stimulus, and approximately 30 seconds afterwards to allow the researcher to measure the time from the stimulus until normalization.

During the pilot study, it was noted that there was often a pause between the rate increase and the following slowing phase of the heart rate response. From this pilot study, a scoring grid was devised (Appendix D) to enable the investigator to extract the data from approximately 150 sheets of polygraph paper per subject onto a single sheet. The data coding process is described in Chapter Four.

Summary

This experimental study used healthy volunteers in a laboratory setting. Each subject spent an entire night in the laboratory while connected to a polygraph machine measuring ECG, EOG, EMG, and plethysmograph.

The subjects heard background noise composed of equipment commonly found in ICUs at an intensity equal to those in an ICU.

For six hours subjects were exposed to six alarm sounds per hour. These alarm noises were taped from equipment found in ICUs.

The subject's heart rate and finger volume pulse responses were recorded. Pre-stimulus and post-stimulus values were compared for significance.

CHAPTER IV

RESEARCH RESULTS

This chapter presents the findings of this study. The sample used is described, as well as the process of coding the data and reliability testing. The sample frequencies and statistical analysis are then presented.

Sample Characteristics

Twenty subjects were recruited from a college dormitory. Each was paid 20 dollars for participating in the study. The subjects were not involved in a health profession, denied medication usage, denied known heart disease, and admitted to normal hearing. Several subjects failed to show up and were rescheduled. Due to time constraints, only 18 subjects were used instead of 20.

Ages of the subjects ranged from 18 to 25 years old. The mean age was 20.44 years and the mode was 20 years. Eleven (61 percent) were female and seven (39 percent) were male.

Coding of Data

Each subject's responses to the stimuli were recorded onto polygraphic paper. The polygraph machine ran for 15 seconds before the stimulus and approximately 30 seconds after the stimulus. Each subject was subjected to 36 alarm stimuli. The principal investigator did all the transcribing of the data.

All of the R-R intervals within each of the six pre- and post-stimulus segments were measured with a millimeter ruler and recorded onto a scoring grid. The two pre-stimulus intervals were labeled A_1 and A_2. The four post-stimulus intervals were labeled B_1, B_2, B_3, and B_4. The amplitude of the volume pulse wave form was counted, and the height, in number of boxes, were recorded onto the grid.

The time to recover was also recorded onto the scoring grid. The time to recover measured the time from the alarm sound until the first volume pulse wave form height was equal to the pre-stimulus height.

The predicted response to the stimulus for the heart rate was a rate increase and then a rate decrease. There was found to be a pause between the two phases in many cases. The scoring grid provided a place to state yes or no as to whether a rate increase, a pause, or a post increase slowing occurred. In addition, the speed of the fastest interval, the length of the pause, and the speed of the slowest interval were recorded.

Two other factors were noted for each alarm stimulus. Subject movement occurring before or after the alarm stimulus affected the heart rate and volume pulse wave reaction. It was also noted that a vasoconstrictive response similar to that seen after the alarm sometimes occurred spontaneously before the alarm stimulus. If the subject was vasoconstricted when the alarm stimulus occurred, it would lead to decreased pre-stimulus values and was, therefore, important to note.

Coding Reliability

Interrater and intrarater agreement were checked to establish the reliability of the coding procedure. Each value for A_1 through B_4 was an average of one, two, three, or four values. The heart rate values were required to be measured within ± 1 millimeter (mm) for agreement. For amplitude, the measures needed to be within ± 2 boxes to be considered in agreement.

The criterion for agreement was set at 80 percent for intrarater reliability and at 70 percent for interrater reliability. Due to the complexity of each computation, 70 percent agreement was chosen for interrater reliability. The principal investigator, who had done all the computations, was expected to have a higher degree of agreement and therefore, the agreement level was set at 80 percent. Definitions, criterion, and results of the interrater and intrarater reliability are found in Table 1.

The level of agreement fell below the criterion for reliability two times for the intrarater reliability and once for the interrater reliability. Both raters fell below their criterion level for time to recover. This was due to beat-to-beat variability of wave form height. Each interval value is several heights averaged and the trend was a decrease post-stimulus, then a recovery. Within the control, the decrease, and the recovery, there was considerable beat-to-beat variation. The two pre-stimulus values were rarely identical and the average was not calculated until the end of the coding. The rater then had to measure the time involved. This varied depending on whether A_1 or A_2 was used and whether the rater felt 10 boxes was

Table 1. Results of Interrater and Intrarater Reliability

	Agreement Definition	Criterion	Actual
INTRARATER n=36			
Heart Rate	± 1 mm	80%	99%
Blood Flow	± 2 boxes	80%	99%
Time to Recover	± 2 seconds	80%	72%
Rate Increase	Agreement	80%	97%
Number of Beats	± 1 beat	80%	90%
Maximum Speed	± 1 mm	80%	100%
Pause	Agreement	80%	86%
Pause Length	± 1 mm	80%	100%
Post Increase Slowing	Agreement	80%	72%
Maximum Slowing	± 1 mm	80%	94%
Movement	Agreement	80%	88%
Vasoconstriction	Agreement	80%	94%
INTERRATER n=18			
Heart Rate	± 1 mm	70%	84%
Blood Flow	± 2 boxes	70%	97%
Time to Recover	± 2 seconds	70%	61%
Rate Increase	Agreement	70%	94%
Number of Beats	± 1 beat	70%	91%
Maximum Speed	± 1 mm	70%	100%
Pause	Agreement	70%	100%
Pause Length	± 1 mm	70%	100%
Post Increase Slowing	Agreement	70%	94%
Maximum Slowing	± 1 mm	70%	92%
Movement	Agreement	70%	94%
Vasoconstriction	Agreement	70%	83%

close enough to the calculated 10.4 boxes of the pre-stimulus value. The next wave form of that height might not occur for another five seconds. Since this variable was not used for any of the hypothesis testing and because of the coding difficulty, the achieved levels of agreement were accepted for this study.

The principal investigator failed to achieve the 80% level of agreement when recording yes or no to whether a post increase slowing occurred. This variable failed in the intrarater reliability testing probably due to a poor definition. With the rate increase, it was specified that there must be three beats faster than the control to call it a speedup. For the post increase slowing, the definition was there must be a slowing. Young adults generally have a respiratory variation with speeding and slowing associated with inspiration and expiration (for an example of this phenomenon see Figure 5). This speeding and slowing was seen before the stimulus and after the speed-up. It was difficult in some cases to determine whether the heart rate had really slowed or whether the slowing was part of the normal respiratory arrhythmia. Again, since this variable was not used for any of the hypothesis testing the 72 percent level of agreement was accepted.

Data Presentation

The following section presents the data collected from this study. Frequency data are presented first. This includes the number of subjects who experienced rate increases, pauses, and post increase slowings. Along with these are the number of beats of the increase

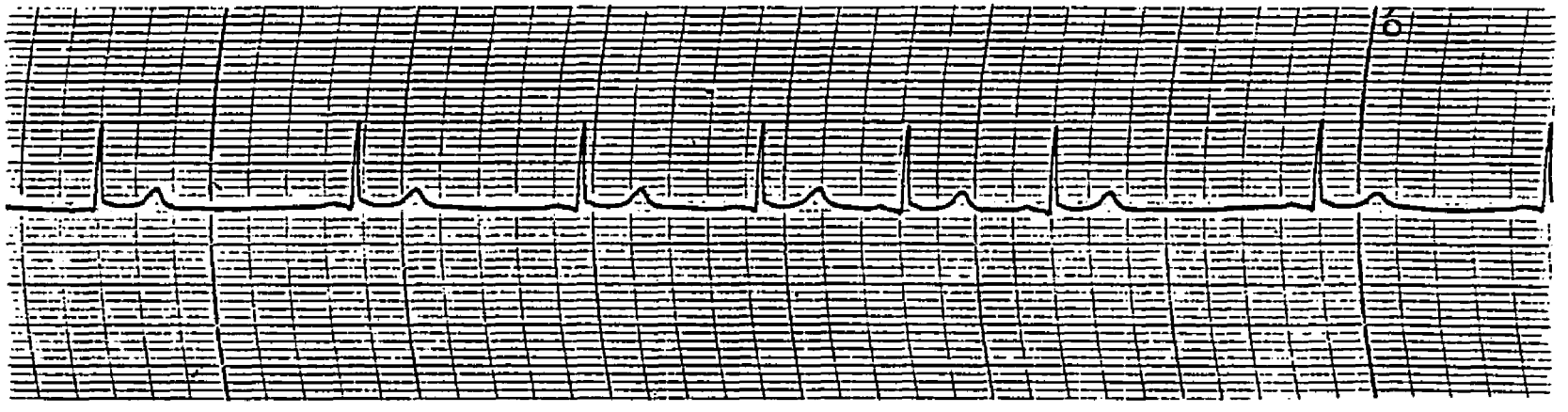


Figure 5. Example of Respiratory Arrhythmia

This irregular rhythm occurred spontaneously. It was not in response to an alarm stimulus.

and the differences between the fastest interval and the control, and the slowest interval and the control. The length of time to recover, the presence of movement and the presence of vasoconstriction prior to the stimulus are given.

Next the average values for A_1, A_2, B_1, B_2, B_3, and B_4 are given, along with the standard deviations and case numbers for both heart rate and blood flow. The blood flow decrease has been calculated in percentages of the control value. Finally the repeated measures analysis of covariance and t-test results are presented.

If data were complete, there would be a total of 648 alarm stimuli. However, several of the alarm stimuli have missing data. For six alarms all data are missing. Subject four discontinued his electrodes when five stimuli were yet to be given. Those five stimuli were one pressure alarm, one infusion pump alarm, one telephone ring, and two cardiac monitor alarms. The sixth piece of missing data was a telephone stimulus during the fifth night. It was missed because the principal investigator could not hear the ring from the next room and therefore did not know where the stimulus occurred on the polygraph paper. Without these six cases, the alarm totals are: ventilator pressure alarm, 107; ventilator disconnect alarm, 108; infusion pump alarm, 107; telephone, 106; cardiac monitor alarm, 214; all alarms, 642.

Within a single alarm stimulus, artifact due to movement would occasionally make it impossible to accurately measure the length of the R-R intervals or the height of the volume pulse wave for one of

the time periods. Therefore, the number of alarm stimuli used for data analysis varies from one time period to the next.

Example of Polygraph Printout

Figure 6 shows a sample of the actual data. The top wave form is the volume pulse wave form. The bottom line shows the heart rate. Each tall spike on the heart rate line is an R wave. The distance between the R waves is measured to give the R-R interval. The line above the heart rate is the time line with each short spike equalling one second. The thick mark along the time line (with M over it) is where the alarm stimulus occurred, in this case, the cardiac monitor alarm. The slash markings along the time line are the markings representing 2.5 second intervals after the stimulus.

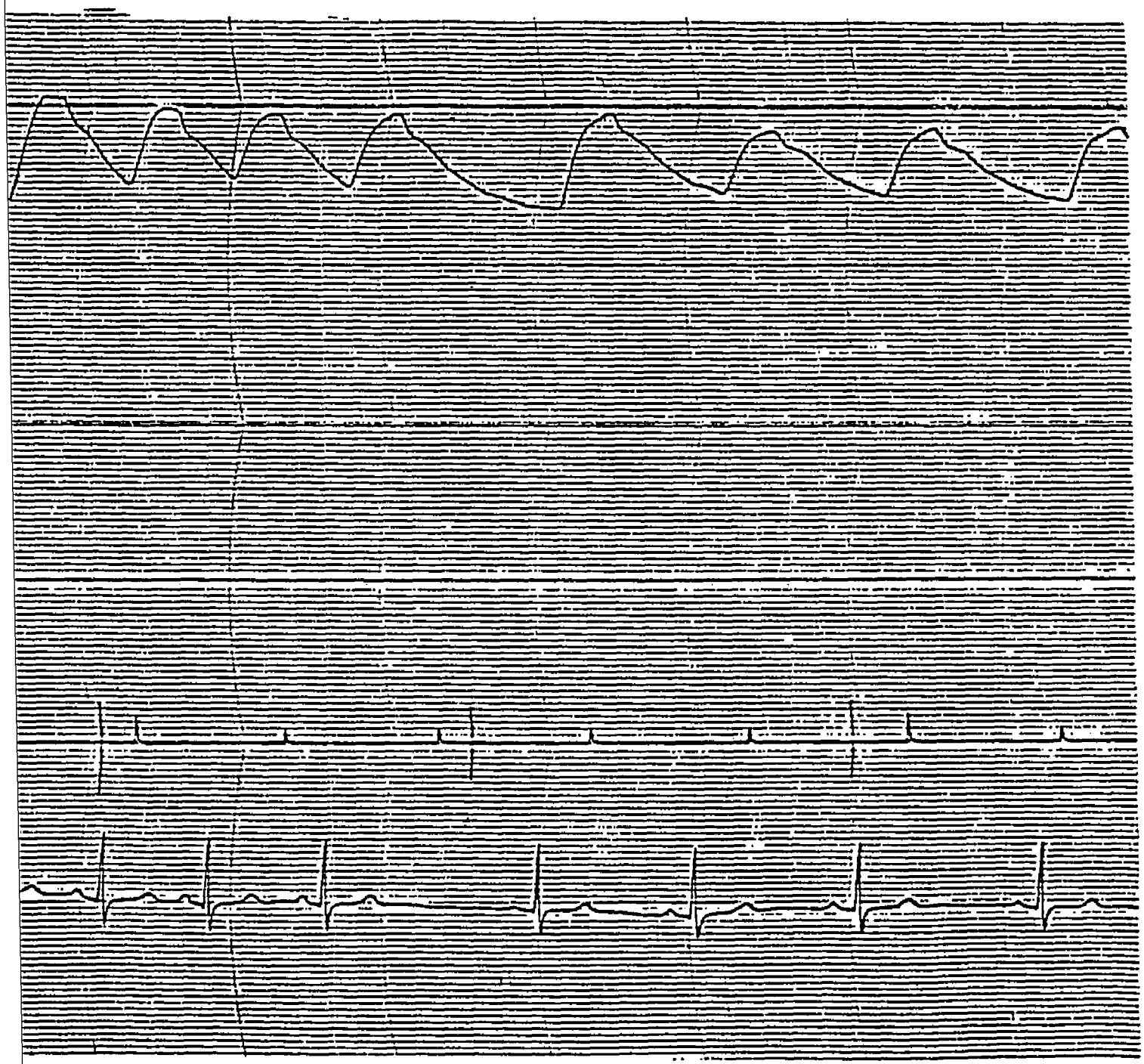
Heart Rate Response. After the stimulus marker, the R-R intervals clearly get shorter than before the stimulus for four intervals. After the short R-R intervals, there is a pause. After the pause, the R-R intervals get longer than those before the stimulus. The last interval on the page is clearly longer than the pre-stimulus values.

Volume Pulse. The finger volume pulse wave form clearly decreases in height after the alarm stimulus marker. The height of the wave form has not yet normalized at the end of this example which is nine seconds post-stimulus.

Post-Stimulus Rate Increase

A rate increase was defined as at least three beats in a row where the R-R interval was shorter than the average of the two

Figure 6. Example of Polygraph Printout



pre-stimulus rates. The number of beats which were faster was also recorded. An increase in rate occurred 47.7 percent to 75.0 percent of the time depending on the alarm, with the infusion pump alarm having the lowest percentage and the ventilator disconnect alarm having the highest percentage. When all alarm stimuli were grouped together, a speed up occurred 64.9 percent of the time (Table 2).

The average number of beats of increase ranged from 5.80 beats for the infusion pump alarm to 8.87 beats for the ventilator pressure alarm. The average number of beats of increase for all the alarms grouped together was 7.07. In 11 out of 642 alarm stimuli, the speedup was prolonged and lasted until the paper stopped. In these cases the number of beats of increase is unknown and has not been averaged into the grouped data.

The maximum speed for each alarm stimuli was recorded only if the subject had had a three or more beat increase. This is the shortest R-R interval measured during the increase period. This short R-R was then subtracted from the average pre-stimulus value (AVHRA). This showed how much faster the increase was over the control value. This number ranged from 5.00 millimeters (mm) for the infusion pump alarm to 6.43 mm for the ventilator pressure alarm, with an average value for all five alarms of 5.85 mm.

Pause Between Rate Increase and Decrease

It was noted during the pilot study that in some instances a pause occurred between the rate increase and the decrease phase of the heart rate response. This pause did not occur consistently,

Table 2. Frequency of Post-Stimulus Rate Increase

	Occurrence of Rate Increase		Length of Rate Increase		Number of Beats of Increase		Non-Occurrence of Rate Increase	
	f	(%)	Max Length (mm)	AVHRA–Max Len. (mm)	Mean	Prolonged Response[a]	f	(%)
Ventilator Pressure Alarm (76 dB(A)) n=107	80	(74.8)	18.39	6.43	8.87 (n=76)	4	27	(25.2)
Ventilator Disconnect Alarm (76 dB(A)) n=108	81	(75.0)	18.54	5.94	6.95 (n=80)	1	27	(25.0)
Infusion Pump Alarm (68 dB(A)) n=107	51	(47.7)	20.06	5.00	5.80 (n=51)	0	56	(52.3)
Telephone (62 dB(A)) n=106	69	(65.1)	18.59	5.99	8.24 (n=65)	4	37	(34.9)
Cardiac Monitor Alarm (70 dB(A)) n=214	136	(63.6)	19.46	5.70	5.92 (n=134)	2	78	(36.4)
All Alarms n=642	417	(64.9)	19.01	5.85	7.07 (n=406)	11	225	(35.1)

[a]Prolonged Response refers to those cases where recovery had not occurred at the time the paper stopped.

and one subject had no pauses for any of the 36 alarm stimuli. The pause occurred in response to 29.9 percent of the infusion pump alarms for the lowest response rate and 51.9 percent of the time in response to the ventilator disconnect alarm for the greatest response rate (Table 3).

The length of the pause was measured, and that length minus the average of the two pre-stimulus values (AVHRA) gives the amount that the pause is greater than the control. The pause length is an average of only those alarms where a pause occurred. The range of the increase in length was from 6.63 mm for the infusion pump alarm to 7.55 mm for the ventilator disconnect alarm. The average lengthening for all alarms combined was 6.95 mm.

Post Increase Slowing

Post increase slowing was defined as R-R intervals longer than the pre-stimulus value. This was not always easy to identify. Although in many instances there was a clear slowing, many young adults have a respiratory arrhythmia causing normal slowing and speeding of the heart rate. A slowing occurred in 39.3 percent for the infusion pump alarm to 62.6 percent for the ventilator pressure alarm. For all alarms, a slowing occurred in 55.3 percent of the cases (Table 4). This variable was only reliable at 72 percent for the intrarater reliability testing.

The maximum slowing measured the longest R-R interval within the slow phase and was measured in millimeters. It was only measured for those alarms where a slowing occurred. From the slowest interval,

Table 3. Frequency of Pause Between Rate Increase and Decrease

	Pause Present	Length of Pause		Pause Not Present
	f (%)	Length (mm)	Length-AVHRA	f (%)
Ventilator Pressure Alarm (76 dB(A)) n=107	51(47.7)	30.80	6.69	56(52.3)
Ventilator Disconnect Alarm (76 dB(A)) n=108	56(51.9)	31.68	7.55	52(48.1)
Infusion Pump Alarm (68 dB(A)) n=107	32(29.9)	30.90	6.63	75(70.1)
Telephone (62 dB(A)) n=106	46(43.4)	30.74	6.69	60(56.6)
Cardiac Monitor Alarm (70 dB(A)) n=214	100(46.7)	31.38	6.99	114(53.3)
All Alarms n=642	285(44.4)	31.18	6.95	357(55.6)

Table 4. Frequency of Post Increase Slowing

	Slowing	Length of Slowing		No Slowing
	f (%)	Max (mm)	Max-AVHRA (mm)	f (%)
Ventilator Pressure Alarm (76 dB(A)) n=107	67(62.6)	31.52	6.57	40(37.4)
Ventilator Disconnect Alarm (76 dB(A)) n=108	63(58.3)	31.41	6.49	45(41.7)
Infusion Pump Alarm (68 dB(A)) n=107	42(39.3)	30.67	5.35	64(60.7)
Telephone (62dB(A)) n=106	56(52.8)	30.89	6.24	50(47.2)
Cardiac Monitor Alarm (70 dB(A)) n=214	127(59.3)	30.91	5.93	87(40.7)
All Alarms n=642	355(55.3)	31.09	6.13	287(44.7)

the average of the pre-stimulus values (AVHRA) is subtracted to show how many millimeters longer than the control value, the slowest interval is. The maximum slowing interval ranged from 5.34 mm longer than the control for the infusion pump alarm to 6.57 mm longer for the ventilator pressure alarm.

Time to Recover

The time to recover was measured in seconds, from the alarm stimulus until the amplitude of the volume pulse wave equalled the pre-stimulus values. In 114 of the total 642 alarms the subject had no response. In 97 of the total 642, the diminished size of the pulse wave was still present when the paper was stopped, so that the actual time is unknown. The no response group and prolonged response group were removed for calculation of time. The shortest average recovery time was 16.72 seconds in response to the cardiac monitor alarm. The longest average recovery time was 19.84 seconds in response to the telephone ring. The average time to recover for all alarms was 18.22 seconds (Table 5).

The subjects' non-response rate was not evenly distributed over the alarms. Of the 107 infusion pump alarm stimuli, the 18 subjects failed to respond with a decreased blood flow 42 times. The greatest response was to the ventilator pressure alarm, where the subjects had no response only 10 times out of 107 alarm stimuli. The ventilator pressure alarm had the highest incidence of having the blood flow reduction still present when the polygraph machine

Table 5. Frequency of Time to Recover

	Response f (%)	Time (Sec)	No Response f (%)	Prolonged Response[a] f (%)
Ventilator Pressure Alarm (76 dB(A)) n=107	71(66.4)	19.34	10(9.3)	26(24.3)
Ventilator Disconnect Alarm (76 dB(A)) n=108	80(74.1)	19.50	12(11.1)	16(14.8)
Infusion Pump Alarm (68 dB(A)) n=107	56(52.3)	17.14	42(39.3)	9(8.4)
Telephone (62 dB(A)) n=106	69(65.1)	19.84	20(18.9)	17(16.0)
Cardiac Monitor Alarm (70dB(A)) n=214	155(72.4)	16.72	30(14.0)	29(13.6)
All Alarms n=642	431(67.1)	18.22	114(17.8)	97(15.1)

[a]Prolonged response refers to those cases where recovery had not occurred at the time the paper stopped.

was turned off. Of 107 alarm stimuli, the volume pulse wave had not returned to its control value when the polygraph machine was turned off 26 times.

This variable fell below the criterion for reliability for both intrarater and interrater reliability. The intrarater agreement was 72 percent and the interrater agreement was 61 percent.

Movement

Movement of the subject was judged by the artifact in the baseline of the heart rate and plethysmograph channels of the polygraph. Movement occurring before the alarm stimulus occurred is assumed to be a random occurrence. Movement before the alarm stimulus occurred nine of 107 (ventilator pressure alarm), five of 108 (ventilator disconnect alarm), eight of 107 (infusion pump alarm), eight of 106 (telephone), and 12 of 215 (cardiac monitor alarm (Table 6).

Movement occurring after the alarm stimulus could also be random or due to the alarm stimulus. Movement occurred in 20 ± 1 percent of the ventilator pressure alarm, ventilator disconnect alarm and telephone stimuli. Movement occurred after only 10.3 percent of the infusion pump alarm stimuli and 14.0 percent of the cardiac monitor alarm stimuli.

Vasoconstriction

A vasoconstrictive reaction was noted to occur before the alarm stimuli in some instances. This reaction looked very similar to the reaction after the alarm noise. Whenever vasoconstriction was seen before the stimuli occurred, it was noted on the grid as

Table 6. Frequency of Movement

	No. (%)	Before Stimulus (%)	After Stimulus (%)
Ventilator Pressure Alarm (76 dB(A))	76(71.0)	9(8.4)	22(20.6)
Ventilator Disconnect Alarm (76 dB(A))	82(75.9)	5(4.6)	21(19.4)
Infusion Pump Alarm (68 dB(A))	88(82.2)	8(7.5)	11(10.3)
Telephone (62 dB(A))	76(71.7)	8(7.5)	22(20.8)
Cardiac Monitor Alarm (70 dB(A))	172(80.4)	12(5.6)	30(14.0)
All Alarms	494(76.9)	42(6.5)	106(16.5)

either being resolved when the alarm stimuli occurred or being present at the time that the alarm stimuli occurred. In 65.4 to 78.0 percent of the stimuli there was no vasoconstriction prior to the alarm stimuli. Vasoconstriction was present in 6.5 percent to 18.7 percent of the cases (Table 7).

Heart Rate and Blood Flow Responses

Responses to the different alarms are found in Table 8. The mean values for each time interval are presented for both heart rate and blood flow. The standard deviation and the total number of cases are given for each interval for each alarm. The AVHRA and AVFA values are averages of the two pre-stimulus values for the heart rate (AVHRA) and blood flow (AVFA). The AVHRA and AVFA values were achieved by averaging A_1 and A_2 for each subject, then adding and averaging the whole group.

Decrease in blood flow was examined by comparing the post-stimulus value to the pre-stimulus average and looking at the percentage of the control (Table 9). A graph of those values is presented in Figure 7. The average percentages were achieved by taking the percentages of each response to a single stimuli. The percentages were then added and averaged.

The largest decrease in blood flow occurred at the third time interval (5.0 seconds to 7.5 seconds) for each alarm. The smallest percentage during the third interval was 58.0 percent for the ventilator pressure alarm and the largest percentage during the third time interval was for the infusion pump alarm with a value of 77.8 percent. The smallest percentage, or the greatest reduction

Table 7. Frequency of Vasoconstriction Before Stimuli

	No. (%)	Resolved Before Stimulus (%)	Present During Stimulus (%)
Ventilator Pressure Alarm (76 dB(A))	70(65.4)	17(15.9)	20(18.7)
Ventilator Disconnect Alarm (76 dB(A))	81(75.0)	13(12.0)	14(13.0)
Infusion Pump Alarm (68 dB(A))	82(76.6)	18(16.8)	7(6.5)
Telephone (62 dB(A))	74(69.8)	13(12.3)	19(17.9)
Cardiac Monitor Alarm (70 dB(A))	167(78.0)	26(12.2)	21(9.8)
All Alarms	474(73.8)	87(13.5)	81(12.6)

Table 8. Means, Standard Deviations and Case Numbers for Heart Rate and Blood Flow

	HEART RATE			BLOOD FLOW		
	Mean	S.D.	Cases	Mean	S.D.	Cases
Ventilator Pressure Alarm (76 dB(A))						
A_1	24.29	3.35	107	17.60	6.88	107
A_2	23.95	3.45	107	17.38	6.77	107
AVHRA/AVFA	24.12	3.17	107	17.49	6.76	107
B_1	21.31	2.81	107	14.89	6.00	104
B_2	21.91	4.29	107	10.33	4.50	102
B_3	23.86	4.68	106	9.94	4.75	102
B_4	24.38	4.84	107	10.65	4.94	100
Ventilator Disconnect Alarm (76 dB(A))						
A_1	23.91	3.40	108	17.48	6.12	108
A_2	24.34	3.51	108	17.36	6.29	108
AVHRA/AVFA	24.13	3.18	108	17.42	6.12	108
B_1	23.10	2.81	108	17.19	6.86	108
B_2	20.95	3.28	108	11.42	5.40	107
B_3	24.42	4.45	108	10.96	5.50	108
B_4	24.93	4.50	108	11.20	5.61	108

Table 8 Continued

	HEART RATE			BLOOD FLOW		
	Mean	S.D.	Cases	Mean	S.D.	Cases
Infusion Pump Alarm (68 dB(A))						
A_1	24.09	3.50	107	18.09	7.02	107
A_2	24.46	3.45	107	18.39	7.06	107
AVHRA/AVFA	24.27	3.27	107	18.24	6.99	107
B_1	23.78	3.12	107	18.21	6.84	107
B_2	22.80	3.15	107	14.77	5.61	107
B_3	24.33	3.15	107	13.79	5.84	107
B_4	25.31	3.97	107	14.19	5.80	105
Telephone (62 dB(A))						
A_1	24.13	3.12	106	17.41	6.67	106
A_2	23.97	2.96	106	16.80	6.77	105
AVHRA/AVFA	24.05	2.84	106	17.12	6.60	105
B_1	22.76	2.90	106	16.32	6.79	105
B_2	22.23	3.86	106	11.33	5.31	103
B_3	23.97	4.43	106	10.95	5.84	104
B_4	24.74	4.20	106	11.84	5.96	104

Table 8 Continued

	HEART RATE			BLOOD FLOW		
	Mean	S.D.	Cases	Mean	S.D.	Cases
Cardiac Monitor Alarm (70 dB(A))						
A_1	24.39	3.47	214	17.53	6.87	214
A_2	24.38	3.41	214	17.49	6.91	214
AVHRA/AVFA	24.39	3.25	214	17.51	6.84	214
B_1	23.41	3.03	214	17.21	6.66	213
B_2	22.06	3.24	214	12.17	6.24	209
B_3	24.81	4.20	214	11.58	6.29	211
B_4	25.55	4.22	214	12.38	6.44	211
All Alarms						
A_1	24.20	3.38	642	17.61	6.73	642
A_2	24.25	3.37	642	17.49	6.78	641
AVHRA/AVFA	24.22	3.15	642	17.55	6.68	641
B_1	22.96	3.05	642	16.85	6.70	637
B_2	22.00	3.57	642	12.05	5.74	628
B_3	24.37	4.21	641	11.48	5.88	632
B_4	25.07	4.34	642	12.11	5.98	628

Table 9. Blood Flow - Post-Stimulus Percentage of Control

	AVFA	B Value	[a]%
Ventilator Pressure Alarm (76 dB(A))			
B_1/AVFA	17.49	14.89	86.4
B_2/AVFA	17.49	10.33	59.9
B_3/AVFA	17.49	9.94	58.0
B_4/AVFA	17.49	10.65	63.2
Ventilator Disconnect Alarm (76 dB(A))			
B_1/AVFA	17.42	17.19	99.1
B_2/AVFA	17.42	11.42	66.5
B_3/AVFA	17.42	10.96	63.2
B_4/AVFA	17.42	11.20	65.2
Infusion Pump Alarm (68 dB(A))			
B_1/AVFA	18.24	18.21	100.8
B_2/AVFA	18.24	14.77	83.3
B_3/AVFA	18.24	13.79	77.8
B_4/AVFA	18.24	14.19	80.5
Telephone (63 dB(A))			
B_1/AVFA	17.12	16.32	95.2
B_2/AVFA	17.12	11.33	67.6
B_3/AVFA	17.12	10.95	64.9
B_4/AVFA	17.12	11.84	70.7
Cardiac Monitor Alarm (70 dB(A))			
B_1/AVFA	17.51	17.21	99.2
B_2/AVFA	17.51	12.17	70.3
B_3/AVFA	17.51	11.58	66.5
B_4/AVFA	17.51	12.38	71.3
All Alarms			
B_1/AVFA	17.55	16.85	96.7
B_2/AVFA	17.55	12.05	69.8
B_3/AVFA	17.55	11.48	66.2
B_4/AVFA	17.55	12.11	70.4

a Percentages are computed with individual data rather than averaged values, therefore, due to rounding error, computations with means shown do not exactly equal the percent values.

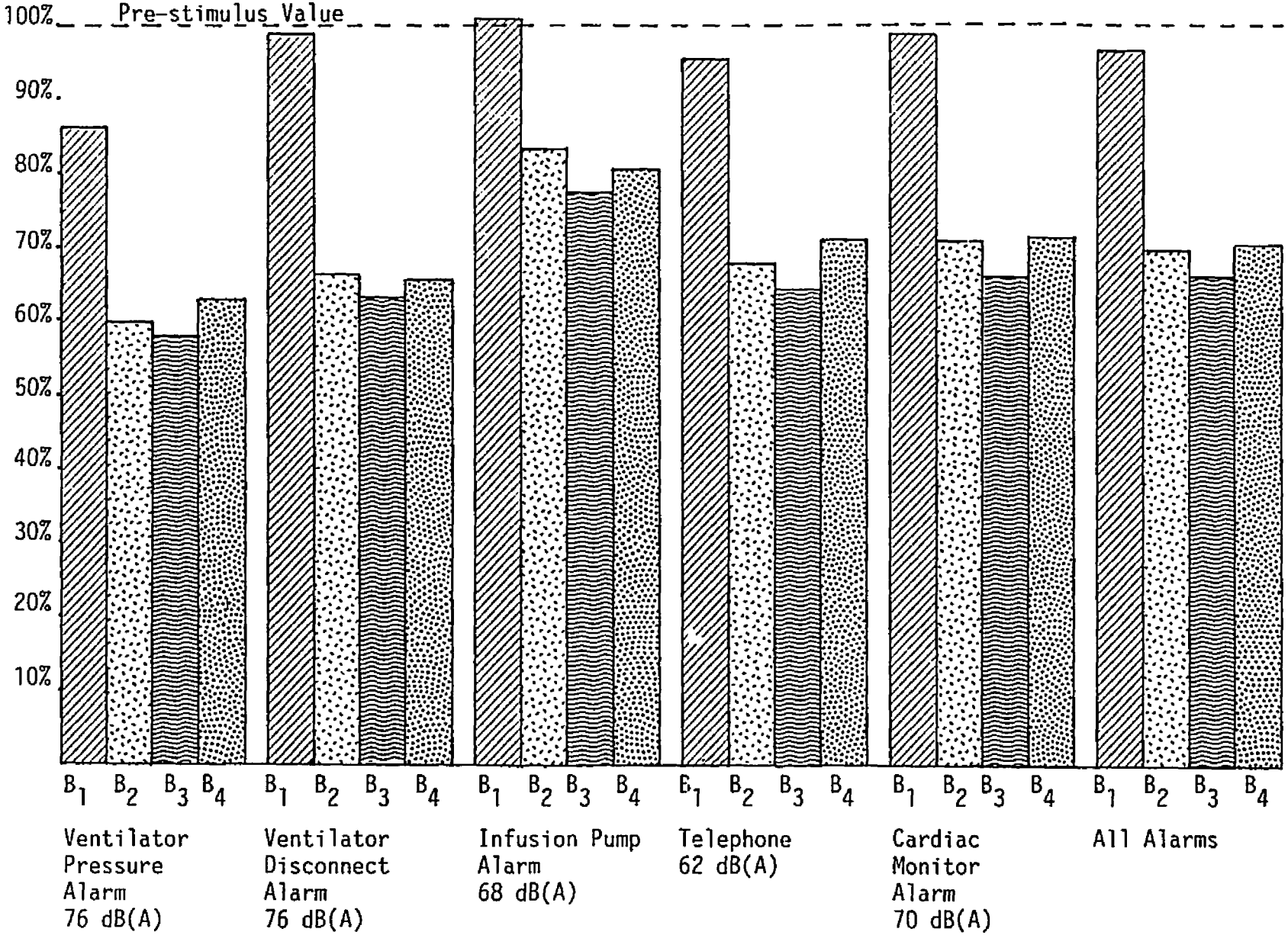


Figure 7. Graph of Blood Flow - Post-stimulus Percentage of Control

of blood flow for all alarms occurred during the third time interval. The blood flow decreased to 66.2 percent of the control.

Repeated Measures Analysis of Covariance

A series of repeated measures six group or 12 group analysis of covariance were conducted using a BMDP program (Dixon 1981). The analysis used the pre-stimulus mean values for heart rate and flow (AVHRA and AVFA) as covariates. The grouping factor was the alarm sequence. In other words, the responses to the first stimulus for each alarm formed the first group, the second stimulus responses formed the second group and so on. The repeated measures were the four post-stimulus responses. In all, 10 analyses, one for each alarm for each of the two response categories, were conducted.

These analyses were done to determine primarily whether the subject's response to the alarm stimuli varied over the six hours of the alarm administrations. In addition, the analysis tested whether there was a significant effect of the repeated measures and/or a significant interaction between the grouping variable and the repeated measures. In all analyses, both the grouping and interaction effects were not significant ($p>0.01$), while the effects of repeated measures were significant ($p=0.000$). In view of these results, the plan to group all similar stimuli together and perform t-tests on the data seemed feasible.

Paired t-test Results

Paired t-tests were performed comparing each post-stimulus value against the mean of the pre-stimulus values. These tests were done for heart rate and blood flow. Each alarm sound was analyzed separately, and then all five alarms were analyzed together. A significance level had been set previously at 0.01.

Table 10 shows the results of the t-tests on heart rate responses for each of the four post-stimulus groups (B_1, B_2, B_3, and B_4) for all alarm categories. The predicted heart rate response was a speeding up and then a slowing down of the heart rate. If that response occurs during the first 10 seconds post-stimulus, the t-values should reflect this by having a positive value initially, then moving to a negative value. Each of the alarms separately and the combined alarms have t-values in the anticipated direction. However, the t-values for the ventilator pressure alarm, the ventilator disconnect alarm and the telephone are not large enough in the negative direction to reach significance. All are significant in the positive direction and the infusion pump alarm, cardiac monitor alarm and the total alarms are significant both for rate increase and decrease.

It was hypothesized that there would be a significant change in heart rate, either a rate increase or a biphasic reaction, a rate increase followed by a decrease, for each of the five equipment noises. The data support all the hypotheses. All five sounds caused a significant increase in heart rate followed by a slowing. The slowing was not universally significant but had a longer time period been recorded, all t-values for alarms might have reached a significant level. The

Table 10. Heart Rate Response: t-test

	t-value	Degrees of Freedom	Prob.
Ventilator Pressure Alarm (76 dB(A))			
B_1:AVHRA	8.16	106	.000
B_2:AVHRA	5.37	106	.000
B_3:AVHRA	.60	105	.552
B_4:AVHRA	-.63	106	.528
Ventilator Disconnect Alarm (76 dB(A))			
B_1:AVHRA	4.00	107	.000
B_2:AVHRA	9.29	107	.000
B_3:AVHRA	-.81	107	.419
B_4:AVHRA	-2.34	107	.021
Infusion Pump Alarm (68 dB(A))			
B_1:AVHRA	2.09	106	.039
B_2:AVHRA	5.09	106	.000
B_3:AVHRA	-.22	106	.824
B_4:AVHRA	-3.68	106	.000
Telephone (62 dB(A))			
B_1:AVHRA	5.44	105	.000
B_2:AVHRA	4.73	105	.000
B_3:AVHRA	.21	105	.835
B_4:AVHRA	-1.80	105	.075
Cardiac Monitor Alarm (70 dB(A))			
B_1:AVHRA	5.23	213	.000
B_2:AVHRA	9.57	213	.000
B_3:AVHRA	-1.56	213	.121
B_4:AVHRA	-4.72	213	.000
All Alarms			
B_1:AVHRA	11.11	641	.000
B_2:AVHRA	15.26	641	.000
B_3:AVHRA	-.98	640	.329
B_4:AVHRA	-5.88	641	.000

three alarms whose t-values became negative but not significanty so, were the three alarms with the highest number of beats of the rate increase. This would necessarily make the slowing occur later.

Table 11 shows the results of the t-tests on the blood flow responses. It was anticipated that the blood flow would decrease post-stimulus, resulting in a significantly positive t-value. As seen in Table 11 in the first 2.5 second period, the change in blood flow for the ventilator disconnect alarm, the infusion pump alarm and the cardiac monitor alarm was not significant. The other two alarms and the total alarms were significant during the first time interval and all five alarms were significant at p=0.000 for the second, third and fourth post-stimulus intervals.

It was hypothesized that there would be a significant decrease in blood flow in response to all five alarm stimuli. All five equipment alarms caused a statistically significant decrease in blood flow for at least 7.5 seconds.

Summary

This study hypothesized that there would be an alteration in heart rate and a decrease in blood flow in response to each of the five noise stimuli. The results from this study supported the hypotheses. The magnitude of the response and the response rate varied with the different alarm sounds. The individual's heart rate responded to the noise by speeding and then slowing, often with a pause in between the two phases. The number of beats which were faster than the control

Table 11. Blood Flow Response: t-test

	t-value	Degrees of Freedom	Prob.
Ventilator Pressure Alarm (76 dB(A))			
B_1:AVFA	7.62	103	.000
B_2:AVFA	15.50	101	.000
B_3:AVFA	15.39	101	.000
B_4:AVFA	13.53	99	.000
Ventilator Disconnect Alarm (76 dB(A))			
B_1:AVFA	.79	107	.429
B_2:AVFA	14.48	106	.000
B_3:AVFA	15.19	107	.000
B_4:AVFA	13.48	107	.000
Infusion Pump Alarm (68 dB(A))			
B_1:AVFA	.16	106	.875
B_2:AVFA	8.07	106	.000
B_3:AVFA	8.80	106	.000
B_4:AVFA	8.17	104	.000
Telephone (62 dB(A))			
B_1:AVFA	3.00	104	.003
B_2:AVFA	11.87	101	.000
B_3:AVFA	10.94	102	.000
B_4:AVFA	9.50	102	.000
Cardiac Monitor Alarm (70 dB(A))			
B_1:AVFA	2.02	212	.044
B_2:AVFA	16.85	208	.000
B_3:AVFA	17.65	210	.000
B_4:AVFA	15.67	210	.000
All Alarms			
B_1:AVFA	6.34	636	.000
B_2:AVFA	29.27	626	.000
B_3:AVFA	29.92	630	.000
B_4:AVFA	26.78	626	.000

varied with the alarm. The subject's volume pulse wave also decreased in response to the alarm as predicted.

A repeated measures analysis of covariance was done which indicated that the subjects responded in the same manner to the alarms over the six hourly administrations. The paired t-test results showed an increase in heart rate then a decrease in heart rate. All the increase responses were significant at $p<0.01$. Two of the alarm sounds and the alarm totals were significant also in the negative direction. The paired t-test for blood flow showed that all subjects decreased their blood flow to statistically significant levels ($p<0.01$) for the second, third, and fourth time intervals.

CHAPTER V

DISCUSSION OF FINDINGS, THE IMPLICATIONS AND RECOMMENDATIONS

Noise has been shown in many studies to be stressful. Noises used in past studies have been continuous or very loud, i.e. gunshot, sonic boom. This study examined what effect sounds commonly heard in an intensive care unit have on healthy subjects during the night hours. It was hypothesized that there would be a statistically significant alteration in heart rate in response to five different sounds, and there would be a decrease in blood flow, representing vasoconstriction in response to the same five sounds. The noises used for this study were the ventilator pressure alarm, the ventilator disconnect alarm, the infusion pump alarm, the telephone, and the cardiac monitor alarm. In response to all five alarm sounds, there was an alteration in the heart rate and a decrease in blood flow. The data supported the hypotheses.

This chapter will discuss how the findings relate to the conceptual framework and the nursing implications of the results. Difficulties encountered during the study which may have resulted in error are reported, followed by recommendations for future research.

Findings Related to Conceptual Framework

This study attempted to establish a positive relationship between noise and a stress response. Noise of varying pitches and intensities had been used in past studies to establish this linkage.

Specifically, this study proposed that equipment sounds commonly found in intensive care units (ICUs) qualified as noise and led to a physiologic response indicative of the stress response. The results of this study, reported in Chapter Four, support this proposition.

Controlling for other factors as closely as possible, the introduction of the alarm stimuli resulted in a change in heart rate that was always significant ($p<0.01$) for the rate increase and not always significant ($p<0.01$) for the succeeding rate decrease. The alarm stimuli also led to a significant ($p<0.01$) decrease in blood flow to the finger as measured by a plethysmograph.

The meaning of this heart rate increase, blood flow reduction, then heart rate decrease is suggested by Davis et al. (1955). They suggested that the sympathetic nervous system was stimulated and the first response is a heart rate increase. Next, the diastolic blood pressure increases which causes a decreased pulse pressure which is seen by the decreased volume pulse. The heart responds to the increased diastolic blood pressure by slowing.

A repeated measures analysis of covariance was done to determine whether the subjects responded differently across the six hours of administration. During the night hours, would the subjects grow accustomed to the noises and stop reacting? This test showed no difference across the hours, which agreed with the studies by Griefahn and Muzet (1978) and Griefahn (1975b). In their studies, the subjects were required to be asleep. The subjects in this study were assumed to be asleep but did not need to sleep.

The noise of the various pieces of equipment were generally unfamiliar to the subjects except for the telephone. The telephone was the softest sound, and sounded as if it were 25 feet from the subject; yet, the subjects responded to the telephone (62 dB(A)) with a greater increase in heart rate, decrease in blood flow, and with more movement after the stimulus than for the infusion pump alarm (68 dB(A)) and the cardiac monitor alarm (70 dB(A)), both of which were louder. The two ventilator alarms (76 dB(A), 76 dB(A)) caused greater responses than the telephone. Each of these stimuli was an annoying sound indicating that a nurse needed to check the machine immediately. It is possible that the telephone had "meaning" to the subjects and caused an increased response. One subject reported he slept well through the night except that the phones kept ringing. When asked about the other 30 sounds he replied "what sounds?". This is consistent with the study by Oswald et al. (1960). Their subjects responded by awakening only to their own name (the familiar one) and slept through the other names which meant nothing to them.

Nursing Implications

This study raises many interesting questions. Do these reactions to noise last long enough to be a threat to the health of a compromised patient? The actual length of time that the reaction lasted is in question. The method used to record that data was not totally reliable. More important than that, even when the size of the finger pulse wave form was equal, the wave form did not always look the same (Figure 8). This might indicate that the pulse pressure

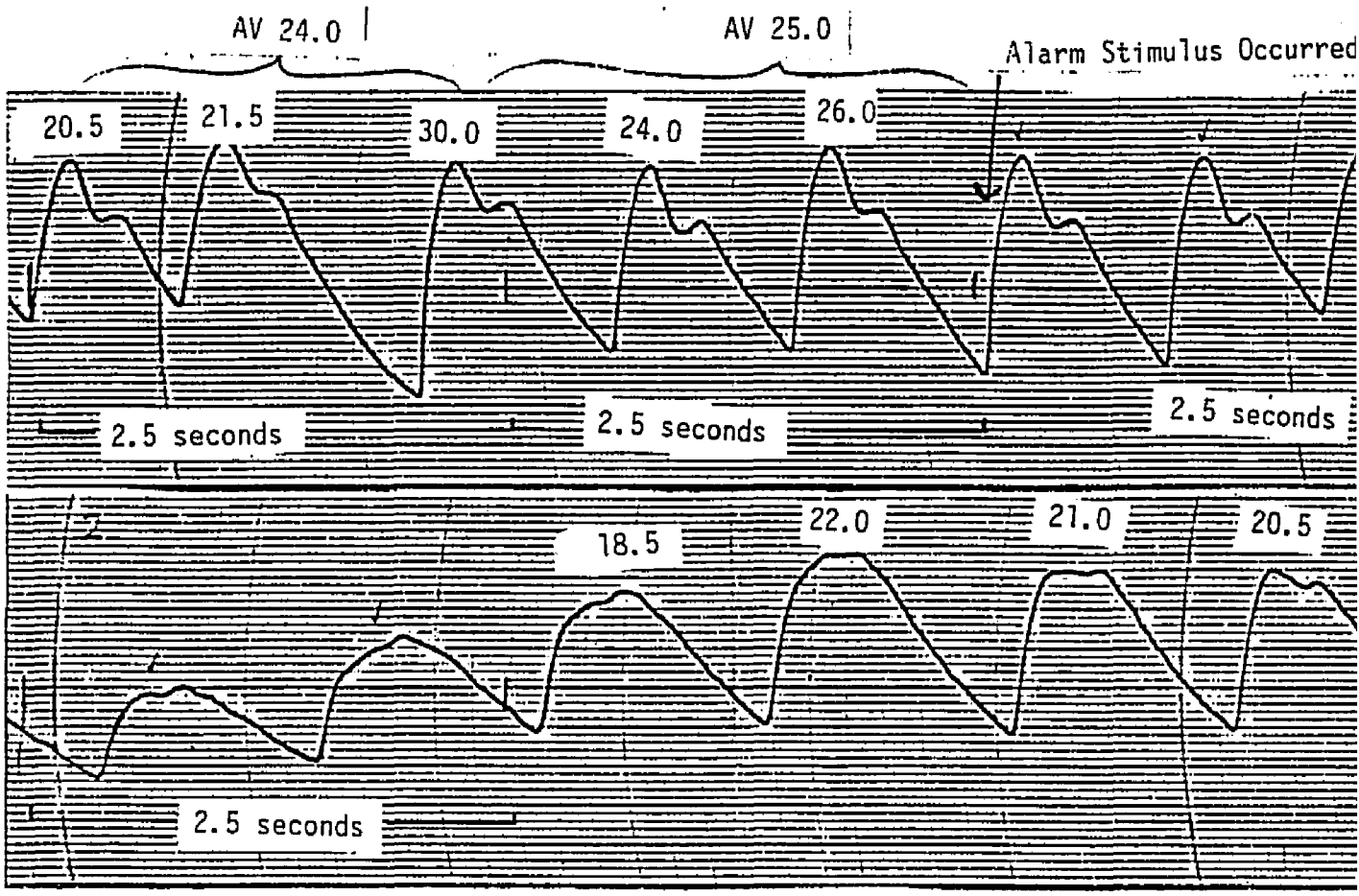
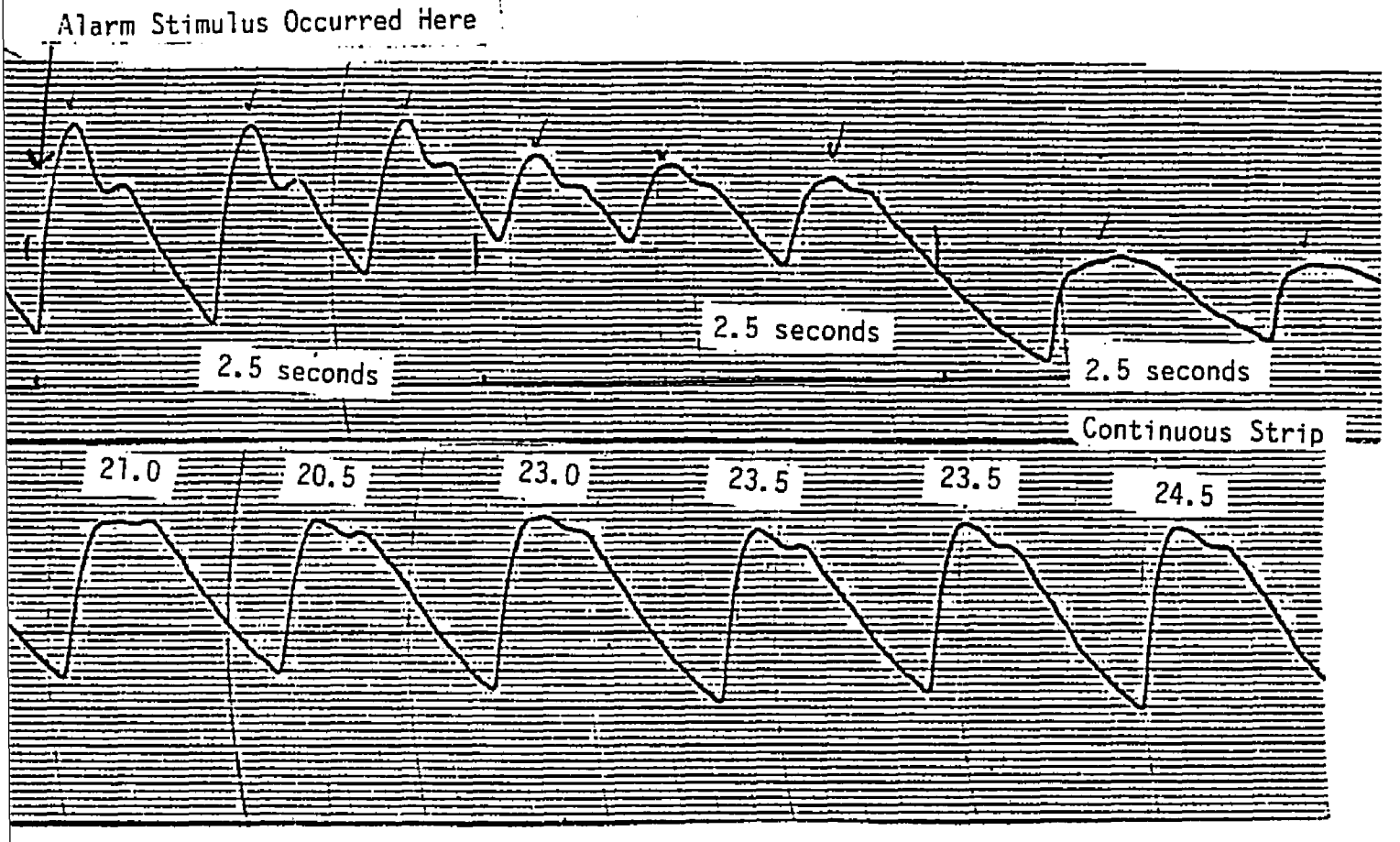


Figure 8. Differences in Volume Pulse Wave Form Configurations Before and After The

Although there is variability within the wave forms in the control time intervals, average height of A_1 is 24.0 boxes and the average height of A_2 is 25.0 boxes. Th average of A_1 and A_2 is 24.5. Although the last wave form on this page is also 24.5 b tall, it is more rounded than the original wave form and has lost its dicrotic notch.



ıtions Before and After The Stimulus

control time intervals, the
of A_2 is 25.0 boxes. The
ɔn this page is also 24.5 boxes
ıs lost its dicrotic notch.

was now equal to the previous pulse pressure but that both the systolic and diastolic pressures were at a different level.

Each stimulus given in this study was a single alarm sound. This permitted measurement of the reaction from a fixed point of time. In hospitals some of the alarms rang until they are turned off. Does an individual continue reacting as long as the alarm continues? Is there summation with each following beep?

Since some subjects spontaneously had reactions similar to the stress response, is it harmful to create this reaction with noise? Finding the spontaneous decrease in blood flow was an accidental finding. The investigator assumed the subjects were responding to something in a dream. When these episodes were seen, they were noted but not analyzed in the same fashion as responses to the stimuli. It is probable that not all episodes were observed because of the intermittent use of the polygraph. The frequency of these reactions is unknown. It is, therefore, unknown to the investigator if these responses are of the same magnitude or duration as those induced by the noise. Despite the presence of other such stress reactions, it is doubtful whether already stressed patients would benefit from repeated stimulation by noise. Whether this stimulation has the potential to be harmful to physiologically compromised subjects is not clear.

Will the critically ill patient react more strongly to the stimuli than healthy subjects since he is worried that the alarm means his health is failing, or will he react less, due to his weakened physical state? This question cannot be adequately answered without

further research, but it probably would depend on the individual. Many critically ill patients are very anxious and scared. Their vital signs often reflect this. If they also have an increased amount of epinephrine circulating due to the stress of the critical care experience, how will they then respond to a sudden loud noise?

Although this study did not test reactions in critically ill individuals, it certainly raises questions that need to be considered. Nurses can protect patients to some extent by being aware of noise and adjusting their routine to minimize the alarm stimuli to which patients are exposed. The following list provides only a few examples.

1. Telephones can be turned down to the low position or a phone with a quieter ring can be installed.

2. If a nurse sets the volume to be infused at 15 cc on an infusion pump, and the pump is going at 15 cc per hour, it will beep in one hour. The nurse could anticipate the alarm and go to that room five minutes before it is set to alarm and reset the machine without the noise.

3. If a patient on a ventilator needs to be suctioned, he requires disconnection from the ventilator. If the alarm silencer is not activated, the alarm will ring. The individual being suctioned will be highly stimulated by the suctioning and the noise will cause minimal problems to him, but for the patient in the next bed or next cubicle, the alarm should be silenced before it starts.

4. If an individual on a ventilator is requiring high inspiratory pressures to ventilate him, and therefore the high pressure alarm is sounding frequently, and the patient does not need suctioning

and is not "bucking" the ventilator, then the pressure limit may need to be adjusted for the benefit of all the patients.

5. When an individual's electrode patches need to be changed or an arterial line needs to be calibrated, the loss of wave form will trigger the machine alarm. If the nurse will anticipate this, the alarms can be turned off before they occur.

6. Patient call bells should be heard clearly in nurse areas but not in patient areas.

7. Machines with particularly annoying sounds might be dampened or altered by a maintenance department.

8. Bedside monitor alarms should generally be turned off in the room so that the patient does not hear the constant beeping of his heart beat unless a nurse is constantly in the room. The nurse watching the monitors will hear the alarm and activate any action which needs to be taken.

9. Keeping the door to a patient's cubicle closed may be very effective in diminishing the noise.

10. Hospital fire alarm bells and overhead paging system should also be considered as a source of noise poluttion and should be altered if necessary to protect the patients.

11. Nurses need to consider equipment noise before assigning the new patient from the emergency department, who is on a ventilator, to the bed adjacent to the acute myocardial infarction patient.

12. The designers of new ICUs need to consider the sound sensitive patient and provide rooms that are isolated from other rooms which contain noisy equipment.

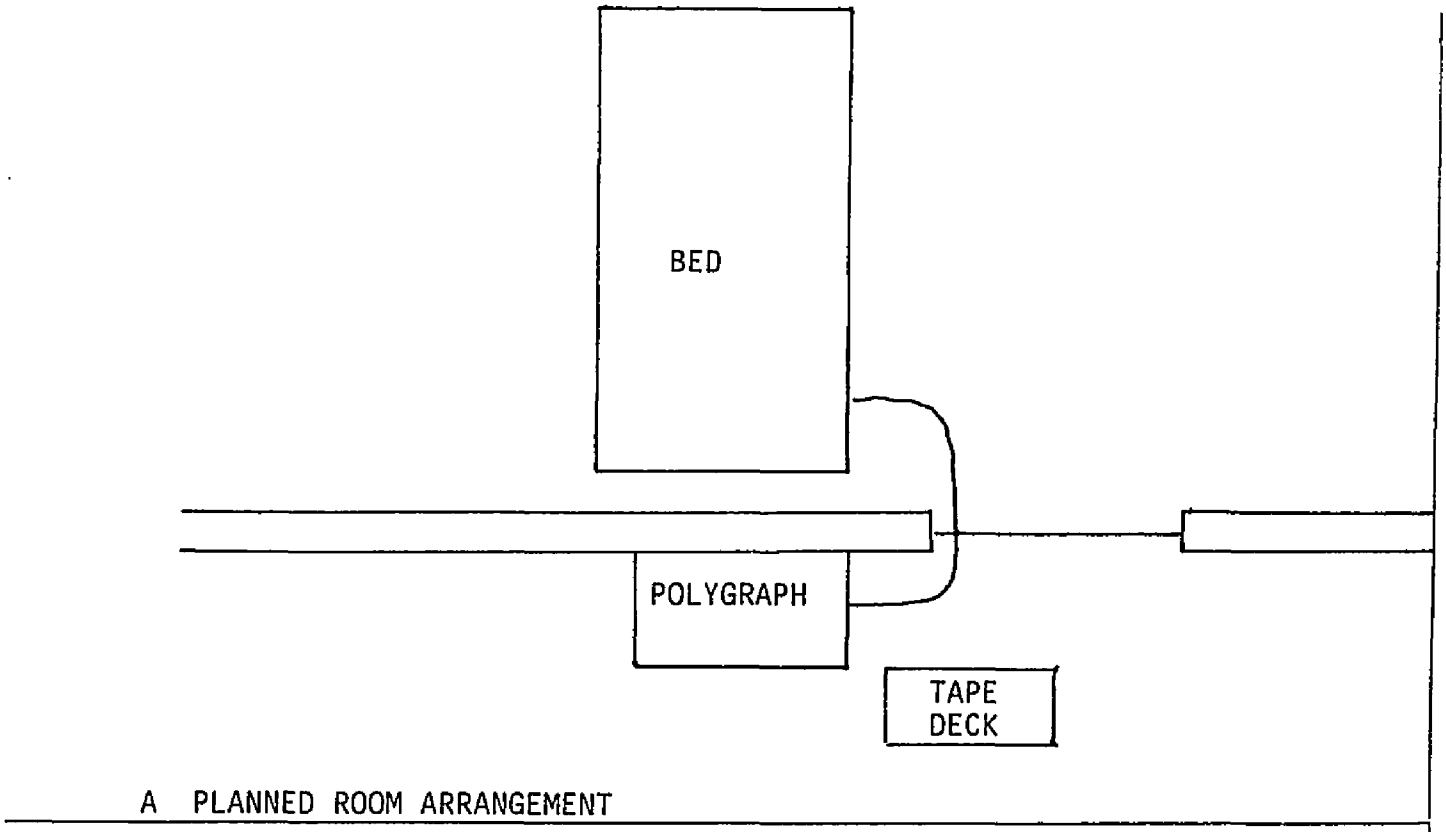
There are many potential ways to decrease stimulation by sound in hospitals. Everyone working in a health care setting needs to take responsibility for preventing excess noise.

Sources of Error

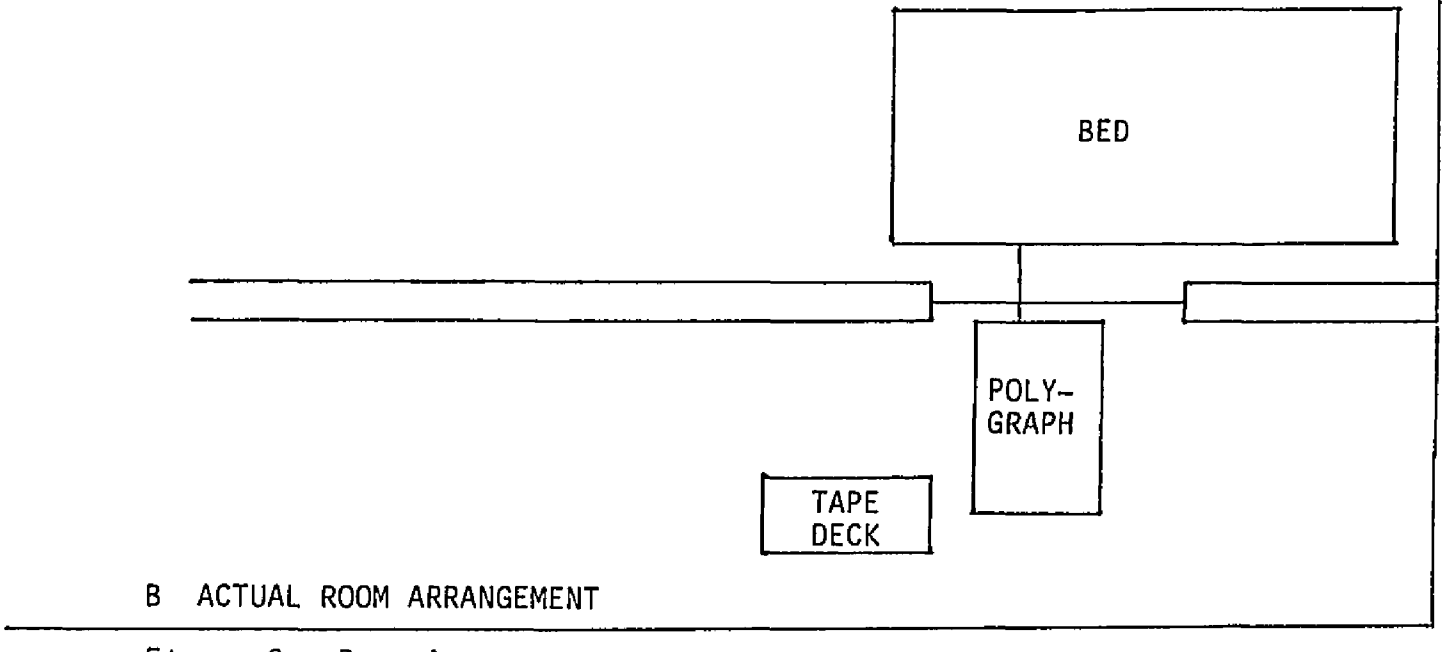
Some unanticipated problems that arose during this study are reported in this section. The first problem encountered was that the cords leading from the subject to the polygraph machine were shorter than desired. The physical arrangement of the room was altered as in Figure 9 from the setup in picture A to the setup in picture B. The wires ran from the polygraph machine, under a wooden door and connected with the subject. With arrangement B, the subject's head was adjacent to the door and he could hear the click of the tape recorder which occurred several seconds before the alarm occurred. One subject who had difficulty sleeping due to the different environment, said she was able to hear the click and prepare for the sound. The preparation could decrease the amount of response, or the click could induce an early response to the click rather than the alarm.

Another problem was that the tape recordings of the ventilator pressure alarm and the telephone ring had some room noise along with the alarm. The amplifier would not play blank tape on the speakers causing a hiss but did carry this background noise which preceded the alarms. Some of the vasoconstriction occurring before those alarms may be due to the sudden introduction of the increased room noise.

A third problem was the inconsistency of the sound equipment. Before each subject arrived, each sound and the background noise were



A PLANNED ROOM ARRANGEMENT



B ACTUAL ROOM ARRANGEMENT

Figure 9. Room Arrangement

calibrated to assure that the levels were accurate. Night to night the gain on the amplifier needed to be moved despite identical setup of the room. The investigator in the adjacent room and several subjects heard and commented on the variation of the sound level. The background noise appeared to be constant for several hours then developed a cyclical fading and strengthening which was unrelated to the length of the tape loop. The alarm sounds also seemed to vary. At times the telephone ring could not be heard in the adjacent room, at times it was heard clearly. The technician responsible for the equipment checked out all the components and found no problems. The sound variations would not occur while he was testing the system.

The facial electrodes were never very helpful. They tended to fall off and since measurements were not being taken from them, the subject was not aroused for replacement. One channel on the polygraph broke during the fourth night. Only three facial electrodes were used afterwards. No conclusions were drawn from the facial electrodes.

The study took place during the summer months. Originally subjects were scheduled nightly. It was not known in advance that the building's air conditioning unit was turned off during the weekend. Two subjects slept in a very hot room. The other weekend subjects were rescheduled.

There were electrical storms during some of the study nights. During the peak of the storm, no alarm stimuli were played so that the thunder would not interfere with subject responses. The research protocol had an hour of background noise without any alarms in the

morning. This allowed the investigator to stop the alarm sequence for 30 to 60 minutes while the storm passed, then to restart the sequence, going into that final hour in the morning.

Two other sounds occurred during the night. The building used for the study was adjacent to a large hospital and occasional sirens were heard. Every night the janitorial service cleaned the building at midnight. This involved flushing 12 toilets in two bathrooms near the research laboratory. Neither the sirens nor the toilet flushing seemed to disturb the subjects or interfere with the research protocol.

Finally, as stated earlier, the use of healthy young adults resulted in the presence of a marked arrhythmia in some subjects. A respiratory arrhythmia is common in children and young adults. It results in a speeding and slowing of the heart rate that coincides with expiration and inspiration. This made it difficult at times to judge slowing and speeding due to noise and to get a constant pre-stimulus value.

Despite the problems mentioned, the study design provided for the control of several factors. The data collected may be considered representative of the effect of equipment alarms on the heart rate and blood flow of healthy adults.

Recommendations For Future Research

Based on this study, recommendations for further research include the following:

1. Repeat this study with healthy subjects over age 60. This would eliminate the respiratory arrhythmia seen with the young. The older population make up a large proportion of critical-care patients.

2. Repeat this study, substituting the use of an arterial line (an invasive procedure) for the plethysmograph. This would yield a direct measurement of the blood pressure rather than the measurement of blood flow.

3. Repeat this study with the alarm ringing more than once. Many alarms normally ring multiple times rather than just once.

4. Conduct an in-hospital study using ICU patients to examine their reactions.

5. Conduct a study to compare individual reactions to different alarms at the same intensity but at different pitches.

6. Conduct a study that examines the reactions of individuals to sounds compared relative to sleep stages.

7. Conduct a study which systematically measures the spontaneous occurrence of vasoconstriction.

8. Conduct a study utilizing a true experimental control group to assess the effects of laboratory simulation versus the effects of the experimental treatment.

Any future study using this methodology needs to consider the problems discussed in the sources of error section. The subject needs to be better insulated from extraneous sounds. The post-stimulus period should be analyzed past 10 seconds.

Summary

The purpose of this study was to test the effect of alarm noise, commonly heard in an ICU, on the heart rate and blood flow of healthy adults in a simulated ICU environment. Eighteen subjects spent one eight hour night each in the laboratory and their responses to alarm noise were measured by polygraphic recording. The study utilized an experimental design with subjects as their own control.

Through the review of literature and conceptual framework, responses were predicted and hypotheses proposed. It was predicted that each of the five sounds would cause an alteration in heart rate, either a rate increase, or a rate increase followed by a rate decrease to below control levels, and the subjects would experience a decrease in blood flow to their finger as measured by a plethysmograph. The five noises used were the ventilator pressure alarm, the ventilator disconnect alarm, the infusion pump alarm, the telephone and the cardiac monitor alarm.

As predicted, and as tested with a paired t-test, there was a significant ($p<0.01$) increase in heart rate in response to all five noises followed by a slowing trend which was significant ($p<0.01$) for two of the alarms but not for three. The combined alarm t-test showed a significant ($p<0.01$) rate increase and decrease. The reduction in blood flow was significant ($p=.000$) for all five alarms plus the combination of alarms. All hypotheses were supported.

This research demonstrated the reactions to noise of healthy individuals. Research needs to be done on ICU patients to determine whether their responses to these noises are greater, smaller, or the

same as healthy subjects. In the meantime, nurses should protect patients from noise at night. Nurses should consider the possibility that their patients may be experiencing stress from the frequent alarms occurring in the environment and take steps to reduce the noise or physically alter the environment.

APPENDIX A

SUBJECT DISCLAIMER FORM

SUBJECT DISCLAIMER

Project Title: The Effect of Equipment Alarms on the Heart Rate and Blood Flow of Non-ill Adults in a Simulated ICU Environment

Principal Investigator: Diane C. Shelton, R.N., B.S.N.

I invite you to participate in a study to determine how non-ill adults' heart rate and blood flow respond to five sounds commonly heard in an intensive care unit.

To be included in this study, you need only be a non-hospitalized adult who does not have a history of heart disease and who is not taking any medications which might affect your heart rate.

As a subject in this study, you will spend eight hours (either 10 pm to 6 am or 11 pm to 7 am) in a room with a bed in the College of Nursing building. The researcher will remain in an adjacent room. You will have five electrodes (small adhesive patches attached to wires) on your face and three electrodes on your chest and a small loose clip on one finger. These devices will allow me to monitor your response to the various sounds played intermittently through the night. You are allowed to sleep and are encouraged to try to sleep, but sleep is not required.

There is no known risk involved with your participation in this study. The conditions are very similar to that which ICU patients experience. Your movement may be somewhat restricted by the wires and you may experience difficulty sleeping in the laboratory environment. The machines do not cause any discomfort, but the electrodes

may cause some skin irritation in individuals with sensitive skin. For your time, you will be paid $20.

You will not experience any benefit from participating in this study, other than financial, but the information gained may help hospitalized patient by identifying the effects on the body caused by sounds.

You are free to withdraw from the study at any time. Please feel free to ask me any questions pertaining to the study. There are restroom facilities available in the research area. Results from your responses will be coded and you will not be identified at any time in this study. Group data will be used in my master's thesis and may be used for future publications.

APPENDIX B

HUMAN SUBJECTS COMMITTEE CONSENT FORM

THE UNIVERSITY OF ARIZONA
TUCSON, ARIZONA 85721

COLLEGE OF NURSING

MEMORANDUM

TO: Diane C. Shelton, RN, BSN
Masters Student
College of Nursing

FROM: Ada Sue Hinshaw, PhD, RN ASH
Director of Research

Katherine Young, PhD, RN
Chairman, Research Committee

DATE: July 20, 1984

RE: Human Subjects Review:

"The Effect of Equipment Alarms on the Heart Rate and Blood Flow of Non-Ill Adults in a Simulated ICU Environment"

Your project has been reviewed and approved as exempt from University review by the College of Nursing Ethical Review Subcommittee of the Research Committee and the Director of Research. A consent form with subject signature is not required for projects exempt from full University review. Please use only a disclaimer format for subjects to read before giving their oral consent to the research. The Human Subjects Project Approval form is filed in the office of the Director of Research if you need access to it.

We wish you a valuable and stimulating experience with your research.

ASH/fp

APPENDIX C

RANDOMIZED TIMES AND ALARMS

Randomized Times and Alarms

Sequence						
1.	:00 D	:14 T	:15 M	:20 P	:49 M	:55 I
2.	:01 M	:25 M	:26 T	:37 P	:42 D	:46 I
3.	:15 M	:21 P	:34 T	:39 D	:40 M	:41 I
4.	:18 M	:34 I	:42 M	:47 T	:48 P	:55 D
5.	:04 D	:05 M	:14 P	:42 I	:45 M	:47 T
6.	:08 I	:15 D	:46 M	:48 P	:55 M	:58 T
7.	:05 P	:12 M	:34 I	:36 T	:45 M	:58 D
8.	:05 T	:19 I	:29 D	:30 M	:31 M	:47 P
9.	:12 D	:21 T	:24 M	:36 M	:42 I	:53 P
10.	:13 I	:27 P	:35 M	:45 M	:46 D	:57 T
11.	:19 P	:29 T	:30 M	:43 I	:47 D	:56 M
12.	:09 T	:19 P	:32 D	:45 M	:53 I	:59 M
13.	:06 D	:15 P	:16 M	:30 T	:38 I	:52 M
14.	:22 M	:25 D	:30 P	:44 T	:49 I	:58 M
15.	:02 T	:07 D	:16 M	:29 M	:52 P	:54 I
16.	:25 D	:32 M	:38 I	:41 M	:43 P	:45 T
17.	:00 D	:09 M	:14 P	:20 M	:49 T	:55 I
18.	:13 T	:14 D	:29 M	:40 M	:43 P	:49 I

KEY: P = Ventilator Pressure Alarm
D = Ventilator Disconnect Alarm
I = Infusion Pump Alarm
T = Telephone
M = Cardiac Monitor Alarm

APPENDIX D

SCORING GRID

	Alarm	HR A1	HR A2	HR B1	HR B2	HR B3	HR B4	Flow A1	Flow A2	Flow B1	Flow B2	Flow B3	Flow B4	Time/ Rate OR	speed Y/N	max rate	Pause Y/N	length	slow again Y/N	min rate	[illegible] Y/N	[illegible]
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