AN INVESTIGATION OF HEART RESPONSE
DURING TRUMPET PLAYING

DISSERTATION

Presented to the Graduate Council of the
University of North Texas in Partial
Fulfillment of the Requirements

For the Degree of

DOCTOR OF PHILOSOPHY

By

Leigh Anne Hunsaker, B.M.E., M.A.

Denton, Texas

December, 1993
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The purpose of this study was to investigate the effects of trumpet playing upon the heart. A Holter monitor was used to record electrocardiograms (ECGs) to examine the heart's response during musical performances and practice sessions.

The study design included two phases: a comparison of the heart rate at rest and while playing a standard etude, and a comparison of heart response while playing selected music in both practice and performance situations. An analysis of the ECGs was performed by a cardiologist and an ECG technician, who examined both the heart rate and the regularity of the heart rhythm.

Results of the first phase of the study showed that the heart rate during trumpet playing was significantly higher ($p < .0001$) than when resting. In the second phase of the study, all but one subject had a faster heart rate during a performance than when practicing the same music.

The medical professionals evaluated the ECGs, medical history, and daily activity logs of subjects to characterize ECG changes as induced by the instrument playing, or as caused by other means. Disturbances in the heart rhythm were more common and more pronounced in performances than in practice. Dramatic, but temporary changes in the heart's rate and rhythm were recorded during trumpet playing. No adverse effects to the cardiovascular system were attributed to trumpet playing.
In addition to the above findings, the ECGs were examined for evidence of a cumulative increase in stress upon the heart during practice sessions. The subjects were instructed to use their customary warm up and to continue practicing in their normal manner. Because information on the routine demands of trumpet playing was desired, the practice procedures and materials were not dictated. A comparison of the first and last five minutes of each practice session showed little change in heart rate or rhythm. No cumulative effect of trumpet playing was found in the heart response of these subjects.
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CHAPTER I

INTRODUCTION TO THE STUDY

Interest in the medical problems of musicians reaches back to stories of Lully's foot and Beethoven's deafness. Individual studies of playing-related health problems have appeared for over a century. Yet until recently, the body of information on the medical conditions of performers has been very limited. Traditionally, the complaints of musicians received little attention from the medical profession, and most musicians have been hesitant to seek medical treatment for these disorders (Brandfonbrener, 1986). In the last 15 years, however, awareness of the medical problems of musicians has increased greatly among physicians, performers, and teachers. This interest has expanded into a specialized field of performing arts medicine.

Lockwood (1989) traced the beginning of performing arts medicine to the Danube Symposium on Neurology and the resulting publication of *Music and the Brain* (Critchley & Henson, 1977). Performers such as Gary Graffman are credited with increasing public knowledge and recognition of the field (Brandfonbrener, 1986; Ledermann, 1989). The subsequent growth of the arts medicine field can be seen in the number of studies and informational articles in professional journals, as well as in the increased emphasis given to this discipline in medical schools and clinics.

Arts medicine programs range from weekend workshops to professional training institutes. The Performing Artists Clinic in Houston and conferences such as the "Playing Hurt" seminar in Minneapolis offer information and
advice for different audiences. One of the most influential forces in the development of arts medicine has been the Aspen Symposium, which has been held annually since 1983 in conjunction with the Aspen Music Festival. This conference brings together physicians, performers, and teachers for concerts, presentation of papers, and master classes dealing with playing-related health problems.

In addition to providing a forum for discussing treatment methods and research findings, the Aspen Symposium became a catalyst for the publication of a new journal, Medical Problems of Performing Artists. Participants in the Aspen meetings also formed the Performing Arts Medical Association, which sets guidelines for clinical training and sponsors research in the field.

Much of the treatment prescribed for playing-related disorders is based on the physician's experience and insight into the demands of the musician's job (Brandfonbrener, 1989). Specialists in performing arts medicine may study current methods of teaching, and observe musicians in practice sessions and performances in order to gain an understanding of the physical stresses involved in playing.

Researchers have sought additional information from professional performers and music students about playing-related health problems. Various surveys have shown that approximately 50 to 75% of these musicians experienced serious conditions (Lederman, 1989; Lockwood, 1989). The most commonly reported problems of string players and pianists were overuse injuries caused by repetitive movement (Brandfonbrener, 1986). Tendonitis and carpal tunnel syndrome were two frequent complaints from players of these instruments.
The problems experienced by wind instrument players, however, are usually of a different nature. Conditions such as protruding teeth, cold sores, and respiratory ailments have long been known to cause considerable difficulty for wind instrument players. In addition to the pre-existing or temporary problems which can cause difficulty, arts medicine research has begun to investigate the physical effects which result from wind instrument playing.

Tucker, Faulkner, and Horvath (1971) examined the effects of brass instrument playing upon the heart's function by examining electrocardiograms (ECGs) of brass students recorded at rest and during instrument playing. The ECGs showed evidence of altered heart response during the playing periods. The authors suggested that the physical strain caused by playing a wind instrument may result in continuing circulatory stress, with harmful results to the player.

The effects of brass instrument playing upon the heart were further investigated by Borgia, Horvath, Dunn, von Phul, & Nizet, (1975). The authors examined the ECGs of French horn players and reported that the alterations found in the ECG rhythms of these musicians indicated that adaptive changes in the heart may occur as a result of the stress of horn playing.

Although unsubstantiated by the data, the conclusions of these ECG studies (Borgia et al., 1975; Tucker et al., 1971) have been presented in the instrumental literature. Tucker, Faulkner, and Horvath's study was reprinted in the Journal of the International Trumpet Guild. Derivative articles concerning these ECG studies have appeared in publications such as
The Horn Call, Music Trades, and the Instrumentalist. In addition, the findings of Tucker et al. have been cited by other medical researchers (Davis, 1975; Wolfe, 1989). Consequently, the idea that brass instrument playing can be harmful to the heart has gained acceptance through repeated reporting.

Because wind instruments are widely used in school music programs, music educators must be concerned with the accuracy of such claims. Any damaging effects of playing wind instruments should be fully investigated. The alarming conclusions of Tucker, Faulkner, and Horvath (1971) have not been corroborated or examined objectively. Further observation of heart response during instrument playing should be combined with a medical assessment of the findings. This paper will examine some of the effects of trumpet playing upon the heart.

Background of the Study

Information from various types of studies has been used to investigate the effects of brass instrument playing upon the heart. Research on the respiratory and circulatory responses of wind instrument players has been examined, in addition to studying the action of the heart itself. The performance anxiety literature also has provided information about the cardiovascular function of musicians.

The various wind instruments have different requirements of air flow and air pressure, and thus cause a wide range of alterations in the player's respiratory and circulatory function. Bouhuys (1964) found that playing brass instruments requires more respiratory effort than playing the same pitches on woodwind instruments. Compression of the lungs and sustained
high air pressures in the mouth were found to be most pronounced in people playing loud, high tones on brass instruments (Bouhuys, 1968).

This compression of the lungs also causes a cycle of changes in the circulatory system. Faulkner and Sharpey-Schafer (1959) noted that playing the trumpet caused circulatory changes similar to those found in the Valsalva maneuver, which is used by physicians as a test of circulatory function. The Valsalva maneuver is the act of compressing the lungs while blocking the airways; this can occur when blowing against fixed resistance, or when straining to lift a heavy object. The Valsalva maneuver causes significant alterations in blood flow, lung pressure, and heart function.

By measuring air pressures in the mouth and esophagus, Faulkner and Sharpey-Shafer (1959) determined that the trumpet is the instrument which requires the highest internal air pressures, and thus causes the greatest amount of stress to the circulatory system. The findings of Faulkner and Sharpey-Schafer (1959) and Bouhuys (1964, 1968) led to the selection of brass instrument players for later research on the cardiac effects of playing wind instruments (Borgia et al., 1975; Tucker et al., 1971).

The cardiovascular function of musicians also has been studied through the research in performance anxiety. A few studies have monitored heart rate continuously throughout performances (Brantigan, Brantigan, & Joseph, 1982; Craske & Craig, 1984; Mulcahy et al., 1990; Neftel et al., 1983). The increase in heart rate observed in the performances was attributed to the effects of adrenaline. In most of the studies which included cardiac data, the researchers recorded only the heart rate and did not further analyze the activity of the heart.
As seen above, the entire cardiopulmonary system is affected by such demanding activities as playing a brass instrument. The use of ECG monitoring makes it possible to obtain more direct measures of the heart's response during instrument playing. An electrocardiogram of the heart's activity can indicate events in both the respiratory and circulatory systems. Two studies (Borgia et al. 1975; Tucker et al. 1971) have used ECGs to examine the heart's function during brass instrument playing.

Borgia et al. (1975) found distinct alterations in heart rhythm (cardiac arrhythmias) in the ECGs of student and professional French horn players. Tucker, Faulkner, and Horvath (1971) observed some differences in players of the various brass instruments. French horn players had many premature heart contractions, while trumpet players had the greatest and most rapid heart rate changes, as well as alterations in heart rhythm. The greater circulatory stress observed in the trumpet players was attributed to the higher mouth pressures and greater air compression required by the instrument. None of the trombone players experienced any cardiac arrhythmias; other brass instruments were not used.

Cardiac arrhythmias are disturbances in the heart's rate or rhythm. Some of these alterations can be hazardous in themselves, while a second group of arrhythmias includes ECG changes which may be either indications of an underlying disorder, or simply temporary changes of no pathological significance. The arrhythmias reported by Tucker et al. (1971) and Borgia et al. (1975) fall into this second category; the presence of such arrhythmias is not necessarily serious. The brass players in these studies were found to experience premature heart beats, heart rates that varied from faster than normal to slower than normal activity, variations in the location of the
impulse which causes the heart to beat, and a phasic arrhythmia characteristic of the Valsalva maneuver.

These arrhythmias may indicate organic heart disease or structural damage. A faster than normal heart rate and premature contractions of the heart, however, can also be caused by physical exertion (Friedberg, 1969), or by the effects of adrenaline (Grau, 1958). Likewise, an arrhythmia related to the phases of respiration is often found in patients with organic heart disease, yet the same arrhythmia is considered a normal response when the Valsalva maneuver is performed. Several arrhythmias associated with heart disease can be produced in a healthy heart under certain conditions.

Because these arrhythmias are sometimes linked to extracardiac factors, it is not possible simply to list each irregularity along with a specific diagnosis. Ungerleider (1960) described an early attempt to rate each arrhythmia individually in which "... it rapidly became evident that this was not only impractical, but thoroughly fallacious." In order to determine the implication of an arrhythmia, it is crucial to consider the context in which the disturbance occurs, as well as the individual's clinical condition.

Rationale

Previous studies (Borgia et al., 1975; Tucker, Faulkner, & Horvath, 1971) have shown that abnormal heart rhythms occur during brass instrument playing. Tucker et al. (1971) suggested that the circulatory stress of brass instrument playing could have persistent effects, even resulting in coronary heart disease. Several aspects of this study, however, do not conform to accepted research practices. A lack of control settings in ECG testing, questionable recording procedures, and the inappropriate application of
medical data seriously undermine the conclusions reached by Tucker, Faulkner, and Horvath.

The Tucker study provided a good deal of new information on the cardiac function of musicians during brass instrument playing. One weakness of this study, however, was a lack of control situations. Many unusual heart rhythms were observed during instrument playing, yet the authors did not provide a comparison with the results of resting ECG tests. In addition, although Tucker et al. did not follow a standard medical practice of extending ECG recording for further control, they represented the arrhythmias found to be indicators of serious conditions.

The significance of an arrhythmia, however, is dependent upon the underlying cause of the irregularity. Temporary changes in heart rhythm can be a function of physical activity. A functional arrhythmia will cease after the triggering factor has been removed (Braunwald, 1980). Although Tucker et al. (1971) claimed that brass instrument playing could have lasting effects upon the heart, no attempt was made to distinguish between organic and functional changes in the heart's response. Comparison of ECGs made during and after playing sessions will distinguish between transient heart rate and rhythm changes, and any persisting irregularities in heart function.

A second unsatisfactory aspect of the Tucker study is that some of the ECGs taken during instrument playing were recorded in unorthodox circumstances. One session consisted of having each subject repeat an exercise without stopping, as many times as he was able (Tucker, Faulkner, & Horvath, 1971). This may not accurately reflect the physical requirements of a real practice.
session. Additional study should employ conventional procedures and materials normally used by the player.

In addition to the lack of control factors, and the unusual manner of practicing used by Tucker, Faulkner, and Horvath, the ECG test results were used to draw conclusions that exceeded the scope of ECG interpretation. Abnormal ECG patterns found during instrument playing were used to make projections about the overall cardiovascular health of the musicians.

After reporting electrocardiogram changes in brass instrument players, Tucker et al. related this circulatory stress to their finding that musicians had a higher incidence of coronary heart disease than the general population. Coronary heart disease, or atherosclerosis, is a condition in which the arteries of the heart become obstructed by plaque formation. The factors contributing to the development of atherosclerosis do not include any type of respiratory exertion (Wilson et al., 1980). In addition, the cardiac arrhythmias reported in brass players are neither an indication nor a cause of coronary heart disease. Although sometimes associated with serious conditions, the occurrence of such arrhythmias is not sufficient to make a diagnosis of heart disease (Crawford et al. 1978; Pantano & Oriel, 1982). Examination of the medical literature will reveal the fallacy of this suggestion by Tucker, Faulkner, and Horvath.

Nevertheless, the evidence of stress upon the heart found by Tucker et al. (1971) during instrument playing should not be dismissed. Marked changes in the heart’s rate and rhythm have been noted during brass instrument playing. Borgia et al. (1975) suggested that more changes might be observed during the actual playing routines of the subjects than were found when they played the set of exercises used in this study. More extensive study using
representative literature may provide additional information on the cardio-
pulmonary stress encountered by players on a daily basis.

The setting in which a musician plays also may be a factor in the
amount of cardiovascular stress experienced. Two studies (Haider & Groll-
Knapp, 1981; Mulcahy et al., 1990) examined the heart response of professional
musicians during orchestra rehearsals and performances. Both studies
reported an increase in heart rate during performances; the cardiac rhythms
were not analyzed in either study, however. Greater cardiovascular stress has
been observed in trumpet players than in players of other instruments
(Faulkner & Sharpey-Schafer, 1959; Tucker et al., 1971). This difference was
attributed to the physical requirements of the instrument. A trumpet player
who experiences irregular heart rhythms while practicing a certain piece
may have increased or additional symptoms when performing the same music.
Both the physical activity involved in playing the trumpet, and the situation
in which the playing occurs may contribute to the stress upon the heart.

Most research examining arrhythmias in brass players, however, has been
conducted in clinical settings. More information is needed about the physical
demands made upon trumpet players in actual practice and performance
conditions. Advances in technology have made it possible to record the ECGs of
performers in different musical settings, without disturbing the playing
process.

The suggestion of Tucker, Faulkner, and Horvath (1971) that brass
instrument playing can adversely affect the heart has not received adequate
scrutiny. Examination of the musicians' medical history and extended ECG
recording can provide the information necessary to study the implications of
any arrhythmias found during instrument playing. Presently, there is no
research which observes the heart function of trumpet players in a context which will allow a medical interpretation of the findings. Therefore, the purpose of this study was to examine the effects of trumpet playing upon the heart, and to assess the clinical significance of these effects.

The research problems were as follows:

1. To determine whether there is a significant increase in heart rate during trumpet playing.

2. To compare the heart's response in two settings: individual practice and a performance.

3. To identify the changes in heart rhythm which occur during trumpet playing.
CHAPTER II

REVIEW OF RELATED LITERATURE

The physiological effects of wind instrument playing upon the heart have been studied by observing the pulmonary and cardiovascular changes that occur during instrument playing, in addition to studying the action of the heart itself. Although the circulatory and respiratory systems are interrelated and function together, each of these systems can be examined individually to organize the information found in cardiopulmonary studies.

The discussion of related research first presents information pertaining to the pulmonary function of wind instrument players. Next, the circulatory changes induced by playing these instruments are examined. The third section contains an overview of the physiology and function of the heart, and information basic to the discussion of cardiovascular research. The fourth section deals with the effects that wind instrument playing has upon the heart. The final section examines the research in performance anxiety which deals with the heart function of musicians.

Research in the Pulmonary Function of Wind Instrument Players

Researchers have examined the the lungs and the respiratory process of wind instrument players, comparing musicians to healthy control groups. In the study of pulmonary function, air pressure is measured in millimeters of mercury (mm Hg). The air in the lungs is divided into four volumes and four capacities (Figure 1). The measurements given are averages for a healthy young man.
The Lungs

The **tidal volume** is the amount of air moved in and out during a normal breath; it is usually about half of a liter.

The **inspiratory reserve volume** is the amount of air that can be inhaled in addition to the tidal volume; it is approximately three liters.

The **expiratory reserve volume** is the amount of air that can be forced out of the lungs after normal exhalation, about 1.1 liters.

The **residual volume** is the amount of air which cannot be expelled from the lungs, approximately 1.2 liters.

![Figure 1. Lung Volumes and Capacities](image-url)
Capacities are made up of two or more volumes combined.

The **inspiratory capacity** is the total amount of air that a person can inhale. It is made up of the tidal volume and the inspiratory reserve volume.

The **functional residual capacity** is the amount of air remaining in the lungs after normal exhalation. It includes the expiratory reserve volume and the residual volume.

The **vital capacity** is the total amount of air that can be moved into and out of the lungs with maximum inhalation and exhalation. It is made up of the tidal volume plus the inspiratory volume and the expiratory reserve volume.

The **total lung capacity** is the entire amount of air that the lungs can contain. It includes the vital capacity and the residual volume (Guyton, 1991).

**Pulmonary Function Tests**

Bouhuys (1964) compared the lung functions of 42 woodwind and brass players with a control group of 58 men. A vital capacity was predicted for each subject based on age and height, then measurements were made. The musicians proved to have larger vital capacities and total lung capacities than their counterparts. All but one brass player had larger vital capacity measurements than expected; some had up to 140% of the predicted value. About two-thirds of the woodwind players exceeded the expected values, with up to 117% of the predicted capacity.

The forced expiratory volumes also were higher for musicians than for the control subjects. The maximum amount of air one can expel in the first second (FEV₁) is a percentage of the forced vital capacity. A normal adult will have an FEV₁ of about 80% (Guyton, 1991). Trained athletes and some wind players, however, have been found to have FEV₁ measurements of over 90%,
which is considered exceptional. Other measurements of lung function examined in the study showed the musicians to be essentially equal to the control group.

Tucker, Faulkner, and Horvath (1971) compared pulmonary function tests of 45 brass players to those of the same control group used by Bouhuys (1964). The functional residual capacity was measured by the helium dilution method and used to determine residual volume and total lung capacity. Timed vital capacity, maximum flow rate, inspiratory capacity, and expiratory reserve volume were also obtained for each subject. The brass players had significantly larger mean vital capacities, residual volumes, total lung capacities, and higher expiratory flow rates ($p < .001$). The mean inspiratory capacity of the musicians was slightly smaller than that of the control group ($p < .2$).

Similar tests of lung volumes and capacities were made for 47 horn players at the Fifth International Horn Workshop (Borgia, Horvath, Dunn, von Phul, & Nizet, 1975). The maximum breathing capacity was greater for professional players than for the non-professionals ($p < .05$). Other lung volumes measured in the study were not significantly different between groups. All of the horn players were then compared to the same control group used in the Tucker, Faulkner, and Horvath study (1971); only age-related differences were found to be significant.

Respiratory Mechanics

In addition to studying the physiology and process of breathing, researchers have collected information about the air flow and air pressure
requirements of various musical instruments. Wind instrument playing is considered to be one of the most demanding activities involving the respiratory system (Bouhuys 1964). The high mouth pressure and sustained air flow required are often greater than those which are used in medical evaluation and diagnosis.

A sustained tone on wind instruments requires a constant air pressure and a steady air flow rate. Bouhuys (1964) investigated the relationship between air pressure measured in the mouth and flow rate and found that it is nearly linear, except in loud playing, where the air flow increases more than the pressure. On the brass instruments, successively higher harmonics require greater intraoral (mouth) pressure, but approximately the same air flow rate.

Although the mouth pressure remains constant during a sustained note, the intrathoracic pressure increases as the lung volume decreases. The expiratory muscles compress the lungs until the mouth pressure for the given pitch is reached and the tone is produced. As the lung volume gets smaller, the expiratory muscles must compress further to maintain the same mouth pressure.

The practical playing ranges of wind instruments usually require air pressures above that of the relaxation pressure of the chest and lungs (Bouhuys 1964). Instruments which have greater resistance require vigorous exhalation to play. On trumpet and French horn, the normal playing range is well above the relaxation pressure, and often near the maximum expiratory force, which limits the time a tone or phrase can be continued. When a player "runs out of air," he has actually lost the ability to continue the necessary level of compression.
Instruments such as tuba and flute, which offer very little resistance, require less expiratory pressure but a large flow rate (Bouhuys, 1964). On these instruments, performers must breathe often, and are prone to hyperventilation, especially when playing in the low register.

Unlike most instruments, the oboe has a lower flow rate than that required in normal breathing. While other musicians phrase their music for points of inhalation, the oboe player looks for opportunities to exhale. An oboe player must have enough air in his lungs to obtain the correct pressure, but the flow rate is so small that it is similar to holding one's breath. The oboe player may exhale two or three times before inhaling. The oboe is often considered to be one of the most demanding instruments in terms of respiratory function. However, although it has a very small reed and the greatest resistance of the wind instruments, it does not create internal pressures nearly as high as those found in trumpet players (Bouhuys, 1964; Faulkner & Sharpey-Schafer, 1959).

Faulkner and Sharpey-Schafer (1959) measured arterial pressure, mouth pressure, and intrathoracic pressure in trumpet and oboe players. In normal speech, mouth pressure is about two mm Hg, while the pressure in the lungs is about 20 mm Hg. The trumpet players in this study had mouth pressures of up to 160 mm Hg recorded while playing. The oboe player produced mouth pressures of up to 60 mm Hg.

Similar results were found by Bouhuys (1964). Oboe players in this study had average mouth pressures ranging from 29.4 mm Hg for low notes to 49.5 mm Hg for high notes. The highest mouth pressure recorded on oboe was 80.8 mm Hg. Trumpet players ranged from 11.5 to over 100 mm Hg. Bouhuys obtained these figures by measuring mouth pressures for single tones, including the highest and lowest practical pitches, played at very soft and
very loud dynamic levels. In contrast, Faulkner and Sharpey-Schafer (1959) recorded measurements during continuous playing of arpeggios and short musical phrases.

Because Bouhuys (1964) examined several wind instruments, this study provides a comparative indication of the respiratory stress experienced by players of different instruments. The tuba had the highest flow rate and lowest intraoral pressure of the brass instruments; soprano trumpets in D and A flat had the lowest flow rate and highest mouth pressure averages. The highest mouth pressure recorded was 158 mm Hg, on a muted trombone. Woodwind players had lower average mouth pressures, ranging from 9.7 to 54.4 mm Hg.

In an extension of this study, Bouhuys (1968) obtained simultaneous readings of flow rates and mouth pressures in flute, oboe, recorder, clarinet, bugle, and trombone players. A volume-displacement body plethysmograph was used to measure lung volume and pressure changes. This method involved placing the subject in a sealed chamber, in which lung volume changes were determined from the displacement of air within the chamber. Lung pressure was recorded for a few notes on each instrument and compared with lung volume and mouth pressure changes on the same notes. The chamber used did not allow the players to hold or finger their instruments, so only single tones were used. Mouth pressure was measured by a balloon catheter, a small hollow tube with a tiny balloon at one end. Fleisch flowmeters were attached to the instrument to measure air flow. However, this equipment made some of the instruments difficult to play; indirect measurements of air flow were necessary for flute and oboe.
Most of the instruments tested followed the same air flow and pressure patterns reported earlier (Bouhuys, 1964). However, the clarinet was an exception. It required higher mouth pressures for low notes. Additionally, Bouhuys found that the clarinet and English horn used slightly less air flow for loud notes than in soft playing.

Tucker, Faulkner, and Horvath (1971) measured intraoral pressures of brass players on sustained notes and arpeggios. Trumpet players in this study had significantly higher mouth pressures than horn and trombone players (p < .001). The extreme pressures noted by the authors which measured up to 150 mm Hg for trumpet players were similar to those reported by Faulkner and Sharpey-Schafer (1959).

Summary

Studies of pulmonary function have shown that larger than expected vital capacities and total lung capacities were found in wind instrumentalists, and especially in brass players; this was suggested to be the result of training (Bouhuys, 1964; Tucker, Faulkner, and Horvath, 1971). In addition, trained musicians were able to sustain a steady air flow at higher air pressure levels than amateurs and non-musicians. Bouhuys (1964) suggested that the larger vital capacities found in wind instrument players also may be due to the possibility that individuals with smaller vital capacities might be less likely to continue playing an instrument which requires large amounts of air.

Air flow requirements vary widely among wind instruments. The volume of air usually increases with the loudness level. In general, brass instruments require a larger air flow and higher air pressure than woodwind instruments.
Brass players had greater increases of air flow and mouth pressures than woodwind players when increasing their dynamic level.

Brass instrument players also had a wider range of mouth pressures as well as higher mean intraoral pressures than woodwind players. In most wind instruments, the intraoral pressure increases with both pitch and dynamic level. Mouth pressures were found to be higher for trumpet than for other brass instruments. There were no significant differences in mouth pressures between horn and trombone.

The air flow requirements and relatively high air pressures measured in the mouth and lungs of brass instrument players has led researchers to study the cardiovascular effects of playing brass instruments. The compression of the lungs while playing involves sustained high intrathoracic pressures; such elevated pressures affect the circulatory system and the action of the heart.

Research in the Circulatory Effects of Wind Instrument Playing

The forced expirations used in brass instrument playing can cause changes in circulation and heart function. Compression of the lungs initiates a cycle of altered blood flow and blood pressure, which affects the action of the heart, in turn causing further changes in circulation. Thus, although the circulatory system realistically cannot be separated from respiratory influence, the present section will deal with circulation primarily.

The Circulatory System

The heart is made up of four chambers: the right and left atria, and the right and left ventricles. The atria act as blood reservoirs and primer pumps, which contract to send blood to the ventricles. The ventricles are much
stronger pumps that propel the blood into circulation. The right side of the heart pumps the blood to the lungs; afterward, the blood returns to the left atrium. The left side of the heart sends the blood to the rest of the body. The blood then returns through the veins to the right atrium.

Figure 2. The Circulatory System

This venous return is controlled by peripheral factors such as skeletal muscle contraction, the action of venous valves which function as one way pumps, resistance in the systemic circulation, pressure differences in the thoracic cavity during respiration, and the slight suction resulting from the expulsion of blood from the right atrium.
When any of these factors alter venous return, the heart's function can be affected. The intrathoracic pressure and the action of venous valves are two factors which are affected by wind instrument playing. An increase in intrathoracic pressure can reduce the venous inflow to the heart through the large veins in the neck and abdominal area. This reduction in venous return causes an alteration in right atrial pressure, and reduces the cardiac output—the amount of blood pumped by the heart. However, when venous valves constrict after a few seconds of playing, more blood is sent to the heart, increasing the heart's rate and contracting power (Faulkner and Sharpey-Schafer, 1959). Brass instrument playing can cause notable changes in cardiac output, as well as affecting venous return.

**Circulatory Function of Brass Players**

Several researchers noted that playing the trumpet was found to trigger a Valsalva effect on the circulatory system (Borgia, Horvath, Dunn, von Phul, & Nizet, 1975; Faulkner & Sharpey-Schafer, 1959; Tucker, Faulkner, & Horvath, 1971). The Valsalva maneuver is a phenomenon resulting from inducing high intrathoracic pressures while blocking the airways. This can occur when blowing against resistance, or when "bearing down," such as in childbirth. The Valsalva maneuver causes changes in the circulatory system, in the heart rate and rhythm, and in lung pressure. The circulatory changes include a cycle in which venous return, cardiac output, and arterial blood pressure are altered.

Borgia et al. (1975) found no significant differences in blood pressure measurements taken immediately before and after French horn players.
performed a set of exercises. However, in recording continuous mouth and blood pressures during playing, Faulkner and Sharpey-Schafer (1959) found that wind players experienced the blood pressure patterns found in the Valsalva maneuver. This pattern, noted when a trumpet player blew mouth pressures up to 160 mm Hg, consisted of a sudden drop in arterial blood pressure as the venous valves shut, followed by a gradual increase in arterial pressure as reflexes caused venous valve constriction, sending more blood to the heart. Although the Valsalva maneuvers were more pronounced in high, loud playing, similar blood pressure changes were also noted in phrases using relatively low mouth pressures. Other circulatory changes noted in this study included swift fluctuations of arterial pressure while playing "a series of rapid blasts" on the trumpet.

In addition to the changes in arterial blood pressure, the Valsalva maneuver also affects the volume of blood returning to the heart through the veins. Borgia et al. (1975) suggested that a decrease and sudden resumption of venous return may occur during prolonged playing, subsequently causing premature contractions of the heart.

In a study commissioned by the Vienna Symphony (Haider & Groll-Knapp, 1981), orchestral players were monitored for circulatory stress during rehearsals and performances. Electrocardiograms (ECGs) were recorded for 24 musicians, including six brass players. Two ECG electrodes were placed on the chest wall of each subject and connected to a recording device. This arrangement allowed the researchers to obtain the continuous heart rates of the musicians, but the ECGs could not be analyzed in detail because a standard electrode placement had not been used.
The heart rates for each minute of the recording period was determined, and mean and maximum values were calculated for each subject. A comparison between the heart rate at rest and during instrument playing showed an increase of 25 to 30 beats per minute while playing. In addition, the subjects had significantly higher heart rates ($p < .01$) during orchestra concerts than in rehearsals of the same music. Very high, temporary peaks in heart rate were noted in some musicians while performing.

In addition to the mean and maximum values obtained during instrument playing, the researchers studied the sudden changes in heart rate by examining the interval of time between successive cardiac cycles. The authors reported rapid pulse rate fluctuations which indicated the changing degree of circulatory stress experienced by the musicians. The brass players showed greater rate fluctuations than players of string and woodwind instruments.

The frequent, dramatic changes of heart rates in the wind instrument players found by Haider and Groll-Knapp (1981) were similar to the findings in other studies involving brass players (Borgia et al., 1975; Faulkner & Sharpey-Schafer, 1959; Tucker et al., 1971). The circulatory stress reported by Haider and Groll-Knapp was consistent with the previous descriptions of the Valsalva maneuver produced during wind instrument playing.

Tucker, Faulkner, and Horvath (1971) attempted to relate the circulatory changes found in wind instrument players to their finding that musicians had a shorter lifespan and a higher than normal incidence of coronary heart disease (CHD). The authors reviewed the causes of death among members of a musicians' union. Coronary heart disease was the cause of death for 56.1% of
the musicians, slightly greater than the 53.5% incidence of CHD in the general population. These figures, however, were for all union members; separate statistics for players of wind instruments were not determined.

Coronary heart disease, or atherosclerosis, is caused by deposits of cholesterol in the arteries that supply the heart with blood. Later, fibrous tissue develops in these deposits; they also may become calcified. Behavioral factors which affect the formation of these deposits include smoking, and high cholesterol levels due to diet and exercise habits. Other factors which are highly associated with atherosclerosis are age and high cholesterol levels due to hereditary causes (Wilson et al., 1980).

Coronary heart disease has been examined in the Framingham Heart Study, a longitudinal study of the factors relating to atherosclerosis. Residents of Framingham, Massachusetts have been examined since 1948 in a continuous investigation of the factors relating to CHD (Dawber, Meadors, & Moore, 1951). The Framingham Offspring Study examined the adult children of the original participants for information about the risk factors known to be associated with atherosclerosis (Kannel, Feinleib, McNamara, Garrison, & Castelli, 1979). In both studies, very detailed information was collected on the medical conditions, physical characteristics, and personal habits of each participant.

Both of the Framingham Studies found that smoking was a contributing factor in developing CHD. Smoking causes damage to the lining of the blood vessels, promoting plaque formation and hardening of the arteries. Tucker et al. (1971) mentioned that the high incidence of heart disease could be influenced by the fact that some musicians are heavy smokers. Wind
instrument players, however, have been found to smoke less than other musicians and less than the general population (Navratil & Rejsek, 1968). The medical history of subjects must be taken into account before meaningful conclusions can be drawn.

An additional suggestion by Tucker, Faulkner, and Horvath (1971) was that the physical strain caused by playing a wind instrument may result in continuing circulatory stress. The findings of Borgia et al. (1975), however, do not show any evidence of residual circulatory effects of wind instrument playing.

Summary

Studies of cardiovascular function have shown that arterial blood pressure and venous blood flow are affected while subjects play wind instruments. Blood pressure changes indicative of the Valsalva maneuver have been observed during trumpet and horn playing. These occurrences are very marked in loud, high playing, but also appear in less demanding passages. Researchers measuring arterial blood pressure before and after playing found no indication of persisting changes in circulatory function (Borgia et al, 1975). However, the data from simultaneous monitoring of blood pressure throughout playing sessions (Faulkner & Sharpey-Schafer, 1959; Haider & Groll-Knapp, 1981) showed dramatic differences during instrument playing. Results such as these emphasize the value of continuous monitoring during instrument playing.
The Physiology and Function of the Heart

Observations of lung function and respiratory maneuvers during wind instrument playing have revealed the occurrences of marked changes in the circulatory system. The heart, which pumps the blood, reacts to the blood flow changes induced by the compression of the lungs. The heart's action may be interrupted or altered, causing further changes in the cardiovascular system. Electrocardiograms (ECGs) can be examined to give a more clear picture of the heart's response and any irregularities occurring in its rate or rhythm.

Electrophysiology of the Heart

An electrocardiogram is a tracing of the electrical potentials which cause the heart to beat. The ECG waves represent the movement of the electrical current through the different parts of the heart. When the positive and negative electrical charges inside the heart cells are balanced, there is no electrical flow. This polarized or "ready" state can be altered by the exchange of sodium and potassium ions through the cell membranes. Depolarization, or a discharge of energy, occurs when sodium is pulled into the cells and causes a wave of electricity to flow through the heart. After this discharge, repolarization occurs as the cells return to their original state.

An electrical impulse is emitted from the sinus (SA) node, a small strip of muscle in the wall of the right atrium. The SA node sends the stimulus through the conduction pathways: across the atria, to the atrio-ventricular (AV) junction, and to the ventricles (see Figure 3). A normal heart rhythm originates at the SA node, and has a rate of 60 to 100 beats per minute (bpm).
The electrical impulses which cause the heart to beat can be detected by electrodes placed on the chest at opposite ends of the heart. While the electrical current is flowing through the heart, this movement is recorded on the ECG tracing. A single view of the heart's activity is obtained by one ECG lead, which consists of a positive and a negative electrode. The V₁ chest lead is shown in Figure 4. In this lead, the negative electrode is positioned above the base of the heart, and the positive electrode is placed below the apex; the third electrode is a ground. Other leads can be positioned to examine the heart at different angles. One ground electrode is used, regardless of the number of leads.
The ECG machine will produce a straight line when no electrical activity is recorded, such as before the electrodes are attached. When the electrical flow moves toward the positive electrode, an upright wave is produced. Conversely, when electricity travels toward the negative electrode, the wave will be inverted.
A two lead ECG will depict the heart's electrical activity from two angles simultaneously. One lead will have upright major waves, while the other lead will represent the same activity with a different configuration of the QRS complex, due to the positioning of the electrodes of each lead. Figure 6 shows a two lead ECG strip.

![Figure 6. Leads V1 and V5](image)

**Electrocardiology**

One of the main diagnostic tools in the study of the heart is the electrocardiogram. In analysis of ECGs, several factors are examined. The heart rate, regularity of rhythm, and the uniformity of waves all contribute information about the action of the heart. The major wave configurations can be labelled as follows:
**P wave** - The first wave of a cycle is the P wave. This wave indicates the travel of the electrical impulse to the atria, which causes the atria to contract.

**QRS complex** - is made up of three wave forms: the Q, R, and S waves. It represents the electrical activity in the ventricles. This complex is greater in amplitude and duration than the P wave, because a larger part of the heart is activated.

**T wave** - The wave following the QRS complex represents the recovery state of the ventricles, as the electrical charge returns to its original state. The atria also have a recovery state, but this is usually simultaneous with the ventricular activity, and is thus hidden by the stronger electrical charge of the QRS complex.

![Figure 7. The ECG Complex](image)

The elapsed time between the wave forms is important in the interpretation of ECGs. The graph paper used, and the speed at which the paper moves through the machine are standardized. The voltage of the electrical impulse is indicated by the height of the wave. The time required for the
electrical current to travel from one area of the heart to another is indicated horizontally. Each large square represents .20 seconds; each of the five smaller squares it holds is equivalent to .04 seconds. The heart rate is determined by measuring the interval from one R wave to the next. Figure 8 shows a sample ECG.

Figure 8. Normal Electrocardiogram

As the electrical charge travels away from the atria, the impulse is slowed down at the AV node. This delay gives the atria time to contract and fill the ventricles with blood before the ventricles receive the charge and contract. This period of time is indicated by a straight line between the P wave and the beginning of the QRS complex. The distance from the beginning of the P wave to the beginning of the QRS complex, which includes this delay, is known as the PR interval, or PRI. In normal sinus rhythm, the PR interval is .12 to .20 seconds in duration. The QRS complex is normally .04 to .11 seconds in duration.
Arrhythmias

Abnormal heart rhythms result from disturbances in the initiation or conduction of the impulse which causes the heart to beat. The rate, site of origin, and regularity of the cardiac impulse can be determined from both normal and abnormal ECGs.

Normal sinus rhythm has a rate of 60 to 100 bpm. Rhythms originating at the SA node, but slower than 60 bpm are labelled sinus bradycardia. A sinus rhythm that is faster than 100 bpm is sinus tachycardia. A sinus arrhythmia also originates at the sinus node, but has an irregular rate. In this arrhythmia, the heart rate increases when the person inhales and slows during exhalation. The respiratory maneuvers used in wind instrument playing can trigger this type of irregular heart beat.

Each area of the heart has an inherent rate at which it emits electrical impulses. The site which has the fastest rate will become the pacemaker, controlling the heart's rate. Under normal conditions, the SA node is the pacemaker of the heart. Other areas have a slower inherent rate, but may become irritable and fire impulses at a faster rate, interrupting or taking over the pacemaking function.

Premature beats occur when an area becomes irritable, precedes the impulse from the sinus node, and causes the heart to contract early, interrupting the underlying rhythm. A premature atrial contraction (PAC) appears as a single, early beat in an otherwise normal rate and rhythm (see Figure 9). A premature ventricular contraction (PVC) originates in the ventricles, causing them to contract before the atria have filled the ventricles with blood (see Figure 10). This reduces the heart's efficiency in pumping
blood. The impulse triggering the PVC does not move through the normal conduction route, and thus takes longer to travel. This results in a wide, bizarre QRS complex, with no preceding P wave, because the atria did not contract first.

Figure 9. Premature Atrial Contraction

Figure 10. Premature Ventricular Contraction

A premature contraction is an irritable mechanism, initiated outside of the sinus node, which interrupts the rhythm with an early beat. A delayed beat which originates outside of the sinus node is an escape mechanism. Escape beats are caused when the SA node fails to initiate a contraction, allowing
another area of the heart to provide the electrical impulse for the next heart beat. Escape beats can originate from a site in the atria, the AV junction, or the ventricles. An escape rhythm occurs when one of these areas takes over the pacemaking function and continues to regulate the heart's activity for a period of time.

Arrhythmias may be initiated in more than one area of the heart. The wandering pacemaker arrhythmia occurs when the pacemaker role alternates between the atria and the SA node. Because the electrical charge is coming from different sites, the impulses take different amounts of time to reach the ventricles. This results in different PR intervals from beat to beat, as well as an irregular R to R interval.

In addition to the arrhythmias which are caused by irregularities in the initiation of the heart's electrical impulses, abnormal rhythms can result from disturbances in the conduction of the electrical impulse through the heart. The electrical impulse can be blocked or delayed at the AV node, or within the ventricles. A ventricular conduction delay is called a bundle branch block (BBB). The delay changes the configuration of the QRS complex and causes it to be wider than normal, because the electrical impulse takes longer to travel through the ventricles. A bundle branch block may occur in either the left or right bundle branch.

Electrocardiographic Equipment

Different types of equipment are available to record electrocardiograms under various conditions. A standard resting ECG test involves connecting leads from the patient to an ECG machine in a hospital or physician's office. Such tests, however, can not detect intermittent cardiac arrhythmias
associated with specific activities. Various techniques have been devised to extend electrocardiograph testing to allow the monitoring of active subjects.

An early method of outpatient monitoring was the radio wave transmission of ECG signals to a receiver; this eliminated the need for connecting wires, but obligated the subject to carry or remain near an "ECG brief case" containing the receiver unit. Another disadvantage is that this telemeteric system is subject to radio interference (Holter, 1961).

The Holter Electrocardiocorder was a major development in ECG monitoring. This machine was designed to allow long term, continuous monitoring by relaying ECG signals directly to a portable tape recorder worn on the subject's belt. The use of Holter's monitoring technique is considered to be the best means of diagnosing cardiac arrhythmias in active patients (Braunwald, 1980). Advances in technology have resulted in smaller and more sophisticated models of the monitor, allowing ECG recording in most daily activities.

Holter Studies

Holter recording is used for a variety of purposes such as for follow up observation of recovering heart patients, and for assessing the effectiveness of heart regulating drugs. In addition, Holter monitors are widely used in descriptive studies of various activities or of certain cardiac abnormalities. The protocol and duration of the ECG recording vary with the purpose of the test.

Observational studies describe the presence, frequency, and characteristics of arrhythmias found during specific activities, or among workers in a particular occupation. This type of Holter testing may last from one to six
hours (Wenger, Mock & Ringqvist, 1981). For purposes of comparison, subjects are often instructed to go about their normal routine for a period of time, in addition to engaging in the activity being studied (Mulcahy et al., 1990; Pilcher, Cook, Johnston, & Fletcher, 1983). A log or diary is kept by the subject, listing the time of each activity for later evaluation of the heart's response to these activities (Hombach & Hilger, 1985).

Trained athletes are often studied during workouts or competitions in order to observe the heart's response during physical exertion. Typical studies may monitor the heart function of athletes during a short warm up and an activity from thirty minutes to three hours in duration, followed by about thirty minutes of rest. Holter monitoring has been used during events such as basketball and squash games, as well as during running, cycling, and skiing (Furlanello et al., 1989; Northcote, McFarlane, & Ballantyne, 1983; Pantano & Oriel, 1982; Pilcher et al., 1983).

A few music performance studies have used Holter monitoring equipment with pianists and orchestral musicians (Mulcahy et al., 1990; Neftel et al. 1982). These studies examined the heart rates of musicians during performances; no further analysis of the heart's response was made.

Heart Function of Brass Players

Tucker, Faulkner, and Horvath (1971) examined the cardiopulmonary effects of brass playing. Electrocardiograms were recorded for 45 male trumpet, horn, and trombone students at rest and while playing. The authors analyzed the individual ECGs and compiled information on the changes found in players of each of the three brass instruments. In order to compare the ECG results between the different instruments, the subjects played the same
material, which was transposed to adjust the range. The ECGs were recorded under very controlled conditions. Factors such as dynamics, tempo, breathing points, and the duration of playing and resting periods were predetermined.

Ten of the students had ECGs recorded in an additional session which involved continuous repetitions of an etude. Each player was told to continue playing as long as possible. The average session lasted 33 minutes; ECGs were analyzed for the first and last four minutes of this period.

The ECGs recorded while playing exhibited the sinus arrhythmia characteristic of the Valsalva maneuver. After a breath, the heart rate slowed significantly, then gradually increased to normal or higher than normal rates. These ECGs confirmed previous observations about the Valsalva-type responses in brass players. No information was given about the resting ECGs.

Other changes in the ECGs included premature atrial and ventricular contractions and changes in T waves and in the QRS amplitude. The authors suggested that the PVCs may have resulted from blood being pushed from the lungs into the left ventricle during forced expiration. Most of the PVCs, however, occurred during inhalation. The T wave changes were found to be a function of the Valsalva maneuver. The authors suggested that hypoxia, a lack of oxygen to the heart tissue, can cause a slight flattening of the T wave. In one subject, the T waves became progressively flatter until they inverted; after inhalation, the T waves returned to normal.

In a comparison across the instruments, mouth pressures were found to be higher for trumpet (p< .001) than for horn or trombone. Horn players had most of the PACs, while trumpet players had the greatest and most rapid R to R interval changes, which was attributed to the higher air pressures required
by the instrument. None of the trombone players experienced any irregularities.

The ten students who participated in the continuous playing episode had more premature contractions and more pronounced sinus arrhythmia near the end of the half hour playing session. The authors reported that additional sessions with two students suggested that cardiac arrhythmias are more frequent and more pronounced when the musician is practicing regularly, than in periods of little or no practice.

Although Tucker, Faulkner, and Horvath (1971) provided a complete and detailed identification of the cardiac arrhythmias occurring during instrument playing, less care was taken in their interpretation of these findings. The authors provided no comparison of the resting ECGs with those recorded during instrument playing. Likewise, Tucker et al. reported no symptoms or risk factors of cardiac disease in the subjects, yet they attempted to link the arrhythmias to coronary heart disease, and suggested that brass instrument playing could cause persisting circulatory stress.

The authors drew their own conclusions about the implications of the arrhythmias they identified; no physician interpreted the electrocardiograms in the context of the testing situation and the subjects' clinical condition. All of the arrhythmias reported in the brass players are found as normal responses to the Valsalva maneuver in healthy adults (Lamb, Dermksian, & Sarnoff, 1958; Shaftel, Selman, Kuhn, & Halpern, 1960). The ECG changes reported by Tucker et al. are not sufficient for a diagnosis of heart disease (Crawford et al., 1978, Grau, 1958).
A second ECG study, reported in four articles, was conducted using student and professional horn players at the Fifth International Horn Workshop (Borgia, Horvath, Dunn, von Phul, & Nizet, 1975; Dunn, 1974; Horvath & Faulkner, 1980; Nizet, Borgia, & Horvath, 1976). Seventy-five people participated in an electrocardiographic study which involved performing sustained tones and scale passages on the horn. Lung function tests were made on 47 subjects; information on medical history was obtained from all participants. Eight of the horn players had existing heart problems, but participated in both phases of the study. Unlike the earlier study (Tucker, Faulkner, & Horvath, 1971) both male and female subjects were involved.

Two cardiologists analyzed the ECGs on a blind basis. All of the horn players had the heart rate changes found in the Valsalva maneuver. Other irregularities were found in most of the subjects: T wave changes were the most common occurrences, appearing in 80% of the participants; premature contractions occurred in 20%, and wandering pacemaker activity was found in over 49% of the horn players. The premature contractions and wandering pacemaker occurred more frequently in female subjects (p< .02), and seemed to occur more often after playing above the staff. This was suggested to be due to the smaller lung capacity of the women, which would require more stress on the pulmonary system to produce the same air flow and pressures.

A total of 64 premature contractions occurred during the test. Twenty-seven of these occurred during playing, or while inhaling quickly between phrases. Three premature contractions were observed during the inhalation immediately before the first excerpt was played. The remainder occurred
during brief rests between the exercises. None of the arrhythmias continued after the playing period.

In another discussion of this study, Nizet, Borgia, and Horvath (1975) provided more information about the observed instances of wandering pacemaker. The normal pacemaker of the heart is the sinus node, the point at which an electrical charge from the nervous system is received, causing the heart to beat. The wandering pacemaker arrhythmias in this study were attributed to impulses resulting from the stretch reflexes of the lungs after a full breath. When internal conditions cause other parts of the heart to regulate its rhythm, the new pacemaker alters the P waves of the ECG, indicating this abnormality.

Nearly half (37) of the horn players tested experienced a wandering pacemaker during the session. The ECGs of an earlier study (Tucker, Faulkner, & Horvath, 1971) were re-examined for occurrences of this arrhythmia. This group of male trumpet, horn, and trombone players included 9 subjects (20%) who had instances of wandering pacemaker. Nizet et al. (1975) suggested that the differences in the two groups might be due to the fact that the some of the participants in the horn study were professional musicians and had significantly more playing experience than the student group tested earlier. The report by Borgia et al. (1975) that female horn players were more prone to the wandering pacemaker arrhythmia also may help to explain the difference.

A more recent study (Mulcahy et al., 1990) used Holter monitoring to examine the heart rate patterns of orchestra members and managers during rehearsals and performances of the British Broadcasting Corporation Symphony Orchestra. The 48 subjects included nine woodwind players and nine brass players.
The study was designed to examine the effect of work schedules on heart rate patterns. The authors found higher heart rates among musicians during evening concerts than during afternoon rehearsals. In addition, differences in heart rate were noted in the various works performed. Brass and woodwind players had higher heart rates during music by Rachmaninov and Tchaikovsky, than in a Mozart work. No other specific information was provided about the heart response of the musicians during the concerts and rehearsals.

Summary

A few studies have examined the cardiovascular effects of brass playing with electrocardiographic monitoring. The changes in heart rate and rhythm observed included premature atrial and ventricular contractions, T wave changes, and wandering pacemaker. The heart rate patterns linked with the Valsalva maneuver were related to the intraoral pressures used by the instrumentalists. Trumpet players had the highest mean and peak pressures and experienced the greatest and most rapid heart rate changes.

Horn players seemed prone to arrhythmias such as premature contractions. Female horn players experienced more premature contractions and wandering pacemaker episodes than the male participants in the two studies. However, the authors were not conclusive as to whether these results were due to differences in gender, years of playing experience, or the instrument played.

A limitation of this type of study is the controlled conditions of the research setting. The type of musical exercises used, and the conditions under which they were played may not represent the physical demands of actual practice.
sessions. Both studies suggested that increased cardiac changes could be expected during the participants' usual practice and playing routines.

The authors suggested that some of the arrhythmias found might indicate adaptive changes of the subject to the physical stress of brass playing. The abnormalities observed were consistent and reoccurring for each affected individual. However, none of the irregular heart rhythms persisted after the playing sessions. Similarly, it was noted that blood pressures of wind players were essentially unchanged in a comparison of measures made before and after playing (Borgia et al, 1975). These facts seem to suggest that the changes observed are transitory in nature, and do not indicate a permanent condition in the musicians.

Research in Performance Anxiety

The cognitive, behavioral, and physiological symptoms of performance anxiety have been examined in studies of various activities. In musicians, the physical aspects seem to dominate (Brantigan & Brantigan, 1984). The physiological symptoms of stage fright can include increased heart rate, excessive tension, and hyperventilation. These reactions have a chemical basis, the presence of excessive amounts of adrenaline in the body. Stage fright is a type of situational anxiety. As the body reacts to stress by producing large amounts of adrenaline, sympathetic responses occur in the body. Many studies have attempted to measure the physical responses that result from performance anxiety. The heart rate is an indicator of physical stress, and is often measured to observe the increase in stress experienced by performers. Three studies which included information on the heart rate of performers are representative of the performance anxiety research.
Appel (1976) used thirty graduate piano students in a study of performance anxiety. In a pretest recital, students gave a short performance where pulse rates were measured just before going on stage. Subjects also completed a questionnaire on feelings of anxiety during the event, and were graded on performance errors. Participants were assigned to one of three groups and attended training sessions designed to reduce performance anxiety. One group used music analysis, the second was instructed in relaxation techniques, and the third group acted as a control, receiving no special instruction. In a post-test performance, pulse rate was found to be significantly reduced ($p < .01$) for the experimental group that was given relaxation training. Appel found no significant differences in heart rates of students who were piano majors and those for whom piano was a secondary instrument.

Craske and Craig (1984) obtained more detailed information on heart rate by using a telemetric system to monitor physiological reactions of piano students during performances. In this study, students with a history of performance anxiety were compared to a group of non-anxious students. The students performed alone and for a group of judges. During performances, the heart rate was sampled for ten second intervals; an average rate was recorded for each interval. Three samples were taken before the first note, and four samples were taken during the performance. Increased heart rates were found both before and during the performances in front of the evaluators. Both the anxious and the non-anxious students experienced these increases in heart rate in the performance situation.
**Beta Blocker Studies**

Several studies have examined the effects of beta blocking drugs in controlling the symptoms of performance anxiety. The body's response to a stressful or dangerous situation is controlled by the sympathetic nervous system. Adrenaline and other hormones are released into the body, causing alpha and beta stimulation. Action on beta receptors stimulates the heart and causes its rate to increase. Research with beta blocking drugs has examined the effects of stress by monitoring physiological activity during performance situations. Many of these studies used a double-blind design, comparing a performance with a placebo, which has no physical effects, to a similar performance with a beta blocker. The blocking of beta receptors reduces or eliminates many of the detrimental physical responses to adrenaline. Studies which recorded information on heart function of musicians are included for discussion.

James, Pearson, Griffith, and Newbury (1977) studied the effects of oxprenolol in 24 string players. The subjects performed two pieces, one memorized and the other with music, on two separate occasions. The musicians were given 40 mg of the beta blocking drug on one of the two recitals. Heart rate and blood pressure were measured before each performance. Two judges rated the performances in a blind fashion concerning use of the drug. Each participant also rated his own playing and estimated his own nervousness before and after performing. The authors found significantly lower heart rate and blood pressure in the performances with oxprenolol. In addition, musical performance improved by both objective and subjective measures when the beta blocker was used.
James and Savage (1984) compared the effects of nadolol with diazepam on 33 string players in another study of performance anxiety. Each student chose and performed 15 minutes of music in two identical recitals. One group of students was given diazepam on one occasion and placebo on the other; a second group was given nadolol for one performance and placebo on the other. Students were screened and excluded for nervous illness as well as for contraindications of the medications used in the study. Heart rate and blood pressure measurements were recorded immediately before the performances. Observers rated students for visible signs of nervousness; one judge scored students on different aspects of musical technique. The performers also rated themselves on performance, mood, and physical symptoms of nervousness. As expected, the heart rate was significantly lower, about 15 beats per minute (bpm), in performances with nadolol. Blood pressure was also slightly lower with the beta blocker.

A similar study used continuous monitoring of heart rate during performances with either a beta blocking drug or placebo (Neftel et al., 1982). The subjects wore a Holter monitor to record a continuous ECG during performances. Participants included 22 student and professional string players who had no history of cardiopulmonary or nervous disorders. The musicians performed twice, first with and then without an audience. Half of the subjects were given a beta blocking drug for the first performance; the others received a placebo. All of the subjects performed the second time without an audience or medication.

The ECGs were used to calculate mean heart rates. Both groups had higher heart rates when playing for an audience than when performing alone. The
heart rate increased about 90 seconds before the beginning of the performance: the fast rate remained steady throughout the performance, a fact which surprised the participants. Subjects given the placebo reached a mean heart rate of 140 bpm when playing for an audience. Musicians who were given the beta blocker showed the same pattern of increased heart rate just prior to the performance; however, their mean rates reached about 100 bpm.

One beta blocker study included wind instrument players among the subjects. Brantigan, Brantigan, and Joseph (1982) used student and professional instrumentalists and singers to study the effects of beta blockade and beta stimulation during performance. Telemetric monitoring was used to record the heart rate, and ECG samples were examined for each subject. Tachycardia, or faster than normal rates, occurred in players who took either the placebo or beta stimulating drug, while those taking the beta blocking agent had maximum heart rates within the normal range. The authors reported instances of premature atrial and ventricular contractions with the different medications. However, no information was given on which instruments were involved, so it was not possible to determine how much effect, if any, the instrument itself may have had on the heart's function.

Research with vocalists has shown similar increases of heart rate during performances with a placebo (Gates et al., 1985). The authors suggest that this increase in the heart's work is due in part to the physical activity of singing. Resting heart rate and blood pressure were recorded before and after the performances. During performances, the heart was monitored by telemetry, providing average and maximum heart rates. As expected, heart rates were significantly lower before and during the performances in which beta blockers were used.
Other studies examining the effects of beta blocking drugs in musical performances (Brantigan, Brantigan & Joseph, 1979; Liden & Gottfries, 1974;) reported similar findings. The heart rate, measured either continuously, or immediately before and after playing, is shown to increase significantly in anticipation of stressful events. Beta blocking drugs have been shown to be effective in moderating the high heart rate and other symptoms of anxiety.

Summary

A common reaction to performance situations is a sudden increase of adrenaline, which causes the heart rate to increase dramatically. This effect has been observed in both student and professional musicians (Brantigan, Brantigan, & Joseph, 1982; Neftel et al, 1982). Several studies of performance anxiety recorded heart rate just before the performance. However, equipment allowing unobtrusive monitoring is available. Electrocardiograms can be relayed to a polygraph offstage, or small heart monitors can be worn. Five studies recorded the heart's activity continuously during performances (Brantigan, Brantigan, & Joseph, 1982; Craske & Craig, 1984; Gates et al., 1985; Mulcahy et al., 1990; and Neftel et al, 1982).

Research with beta blockers has provided a comparison of the physiologic activity in performances with no medication, or a placebo, which does not affect the heart's function, to performances with beta blockers which regulate the activity of the heart. Several studies of instrumentalists have included the heart rate as a measure of stress caused by performance.

A study of vocalists attributes part of the increase in heart rate to the physiologic work of singing (Gates et al, 1985). Wind instrument playing makes greater demands upon the cardiopulmonary system (Bouhuys 1964, 1966), but
there is little research on cardiac effects during wind instrument performance. Most of the beta blocker studies have examined string players and pianists, and included only the average and maximum heart rates.

However, Brantigan, Brantigan, and Joseph (1982) examined both the heart rate and rhythm of musicians during live performances. Some irregularities such as premature contractions of the heart were noted. These may have been caused by the resistance of the instruments as noted in clinical studies of brass players (Borgia et al, 1975; Tucker, Faulkner, and Horvath, 1979). More information is needed to determine the amount of cardiac stress caused by playing a brass instrument, as well as any increased or additional changes in heart function caused by the stress of a performance situation.
CHAPTER III

RESEARCH METHODOLOGY

Previous research has shown that wind instrument playing causes changes in the circulatory system and heart response of the musician. The circulatory changes observed by Faulkner and Sharpey-Schafer (1959), and the sinus arrhythmia reported by Tucker, Faulkner, and Horvath (1971) are effects of the Valsalva maneuver, and are related to the air pressures used to play the instrument. The other arrhythmias observed in brass players have not been thoroughly examined, although it has been suggested that changes occurring could be harmful to the player (Tucker, et al., 1971). In order to study the possible implications of these arrhythmias, however, it is necessary to evaluate the heart response during instrument playing in the context of the subjects' overall cardiovascular condition.

The present study identified cardiac arrhythmias during trumpet playing and examined the significance of these altered rhythms. This was accomplished by examining electrocardiograms (ECGs) of a group of trumpet players recorded during instrument playing and other situations. The data considered included the medical profile of each subject, along with the analysis of electrocardiograms recorded during practice sessions, performances, and non-playing periods.

The ECG recorder chosen for this study was the Holter monitor, a small self-contained unit which allows inconspicuous monitoring of active subjects. Because this device was designed for outpatient use, it is simple to operate and
does not require an attending physician or nurse. The Holter monitor uses two chest leads and a ground electrode, which are connected directly into the unit. The ECG signals are recorded on ordinary cassette tapes at one mm per second; at this speed, one side of a standard 60 minute tape will record for 24 hours. The unit is powered by a nine volt battery.

Pilot Study

A pilot study was conducted to determine the feasibility of recording electrocardiograms in a variety of musical settings. A Holter monitor was used to record ECGs of student and professional brass players at the Aspen Music Festival during the 1990 summer season. This was a preliminary study in which the occurrence and character of cardiac arrhythmias were examined in three musical situations, (1) individual practice, (2) a rehearsal or lesson, and (3) public performance.

In addition to confirming the possible use of the Holter monitor, the initial testing allowed a preliminary comparison of the degree of cardiovascular stress experienced during the different musical settings, and between instruments. The pilot study also helped to assess the willingness of people to participate in such testing, and their ease in using the monitor.

Subjects

Seven college students and four professional performers participated in the initial study. The brass players involved were a group of volunteers between the ages of 23 and 41. The instruments represented, and the number of ECGs taken in each situation are summarized below.
Table 1

Pilot Study Subjects

<table>
<thead>
<tr>
<th></th>
<th>Trumpet</th>
<th>Horn</th>
<th>Trombone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>n = 7</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Professional</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>11</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

Preparation of Subjects

Preparation for electrode attachment involved wiping the skin at the electrode sights with alcohol, and cleaning the area with an abrasive pad. Next, five color coded electrodes were snapped on to electrode patches that are treated with a conductive gel. The patches are then placed on the skin, where the gel forms a strong adhesive bond.

Data Collection

In order to examine heart response during instrument playing, ECGs were recorded for a group of brass players. Each participant was asked to use the Holter monitor, first playing his own warm up, and then continuing in a practice session, rehearsal, lesson, or performance. Subjects were asked to practice in their usual manner, with the musical literature or lesson material currently being prepared. A log was kept for each subject, listing the starting time of each excerpt played, for later examination of the ECGs. The lessons, rehearsals, and performances in which subsequent testing took place were Music Festival events. No musical situations were contrived specifically for the purposes of this testing.
Table 2

Musical Settings

<table>
<thead>
<tr>
<th></th>
<th>Practice</th>
<th>Rehearsal</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student</td>
<td>n = 5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Professional</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

On some occasions, Festival rehearsal and performance schedules did not permit the researcher to be present during the event being monitored. In such cases, the subject was shown how to operate the Holter monitor, and given written instructions for preparation and a diagram for electrode attachment which were supplied by the manufacturer. The brass players had no trouble following the procedures, and all of the Holter recordings made during the pilot test provided clear ECGs for study.

Analysis

The ECG tapes were transcribed and analyzed for changes in heart rate and rhythm by an Applied Cardiac Systems Holter Reporter computer system. This program plays the tape at a high speed, reproducing the signals on an oscilloscope, where the wave form of each heart beat is rapidly superimposed upon the preceding ones. Identical wave forms are seen as a single, steady image. Any significant change in the heart rhythm can be seen during this analysis, and marked by the technician for later study. The use of this analyzer makes it possible to examine quickly the data from lengthy tests.
Next, the recording is transcribed to a very compressed format, in which one hour of activity is shown on one page. Extremes in heart rate, periods of low heart rate variability, and premature contractions are identified, as well any events marked by the operator during the superimposition scanning. The ECG technician can then select areas of interest, and print them in real time in standard ECG size and format.

Irregularities in pulse time are identified by an arrhythmia graph analyzer. This produces a very compact graph of the R to R intervals, a minute by minute graph of heart rate, and an hourly arrhythmia summary. Information is graphed along a time line in order to match the heart function with the subject's activities. A Tabulator Summary Report, which calculates occurrences of abnormalities in heart rate and rhythm, and summarizes total test data can be printed.

**Results**

The ECG tapes from the pilot study were analyzed, and examples of both normal and abnormal rhythms during instrument playing were printed. Examples of sinus arrhythmia characteristic of the Valsalva maneuver were found in all of the trumpet players. Premature atrial contractions were noted in one trumpet player, while another experienced several premature ventricular contractions. All of these premature beats occurred during performances. Changes in the T waves of two trumpet players were observed during jazz band rehearsals; similar changes were found in three other trumpet players while practicing the piccolo trumpet.

Changes in heart rate and rhythm were less pronounced in people playing French horn and trombone. The horn players had periods of sinus
arrhythmia, but with less severe changes in the R to R intervals. No other irregularities were found in practice or performances. The trombone player had normal sinus rhythm throughout the test period.

After examining the results of the pilot study, it appeared that further study of trumpet players would provide the clearest examples of the alterations in heart response indicated by ECG monitoring. The trumpet players as a group showed more examples of arrhythmias, and greater extremes of heart rate during instrument playing. This is supported by the research of Tucker, Faulkner, and Horvath (1971), which showed that playing the trumpet caused more cardiopulmonary stress than French horn or trombone playing.

Throughout the pilot study, the only arrhythmia which occurred in practice sessions was the sinus arrhythmia characteristic of the Valsalva maneuver. No increase in cardiovascular stress was apparent in the rehearsal or lesson situations. All of the premature atrial and ventricular contractions observed in the pilot study were recorded during performances. Therefore, the main study will include ECG recording in two playing situations: individual practice and public performances.

The higher incidence of other arrhythmias reported by Tucker et al. (1971) during practice sessions may have been due in part to the nature of the exercises used, and the extreme conditions under which the musicians were asked to play. The use of standard material and conventional methods of practice in the present study should give a more realistic representation of cardiovascular stress encountered by trumpet players on a daily basis.
Main Study

The information gained from the pilot investigation helped to direct the focus of the present study. The main study examined the effects of trumpet playing upon the heart by recording ECGs of trumpet players practicing and performing actual music literature during live situations. This made it possible to study the effects caused by the physiological work of playing the instrument, as well as to observe the additional demands made upon the heart under performance conditions. The research problems for the main study were as follows:

1. To determine whether there is a significant increase in heart rate during trumpet playing.
2. To compare the heart's response in two settings: individual practice and a performance.
3. To identify the changes in heart rhythm which occur during trumpet playing.

Subjects

Participants in the main study were volunteers from a potential subject pool of professional and student trumpet players. All of the participants were 18 years of age or older. An attempt was made obtain a balanced group of subjects, with men and women of different ages and various levels of musical experience; however, no one was excluded on the basis of these characteristics. A total of twenty-four subjects participated in different phases of the study.
Preparation of Subjects

The preparation of subjects for electrode attachment was the same as the procedure reported in the pilot study. The skin was cleaned with alcohol and a scrub pad. Electrodes were connected to electrode patches, which were then placed on the chest.

Data Collection

Prior to the Holter testing, each subject completed a medical profile, which provided the relevant information on cardiac arrhythmia factors for later assessment of the ECG findings. The information in the medical profile includes standard questions concerning the subject's personal and family medical history which are routinely asked by cardiologists. Information on the use of beta blockers was requested on the medical profile; however, none of the subjects used this type of medication during the test. A copy of this form is found in Appendix A.

Twenty-one subjects completed the first phase of the research project, which involved comparing the resting heart rate with the heart rate recorded while playing a standard selection of music. The subjects were given the monitor and music before the test, in order to allow them to become familiar with the process. At the beginning of the testing period, each participant sat quietly for 15 minutes in order to obtain a resting heart rate. Each subject played the same etude, using a metronome. The subjects were told to play straight through the music at the given tempo, ignoring any mistakes. The etude used for this test was a composite piece of standard material including scale passages, rapid articulations on repeated notes, and lip slur patterns.
The maximum heart rate during the control (rest) period was compared with the maximum heart rate during trumpet playing. The maximum heart rate was determined from the six second interval with the highest rate during each of the two periods.

The second phase of the study compared the heart's response in practice and performance. An extended ECG was recorded for twelve subjects in order to evaluate the heart's response in these situations. The data collection process was similar to that described in the pilot study, with the addition of further recording in daily activities of the 12 subjects. For this test, each subject wore the Holter monitor for at least three hours. The ECG recording continued until thirty minutes following the final period of instrument playing in order to examine the possibility of persisting arrhythmias. Each participant kept a log of his activities during the recording period. A detailed account of the practice session was requested for later examination and analysis.

The first 15 minutes of the Holter recording was used as a control period, providing a resting ECG for comparison with later activities. Following the control period, the subject engaged in a practice session and a solo or ensemble performance. The periods of time between and after instrument playing also were examined for additional information on the heart function of each subject. In accordance with Holter monitoring practice described in Chapter Two, the other activities of the musician were not prescribed, nor was the order of events mandated.

For the purpose of this study, a practice session was defined as a period of individual instrument playing in which the subject was engaged in developing or maintaining his musical skills. The material played consisted
of the individual's usual warm up and any other material of his choice, including at least one complete reading of the music to be performed in subsequent ECG recording. Because information on the routine demands of trumpet playing was desired, the practice procedure was not dictated by the researcher. Each subject was instructed to practice in his accustomed manner; no attempt was made to induce any additional physical responses.

A performance was defined as any solo or ensemble musical presentation which is open to the public. No attempt was made to control the music to be performed.

**ECG Analysis**

The ECG interpretation was conducted by two health care professionals: a certified ECG technician and a cardiologist. An ECG technician is trained to identify and interpret ECG rhythms, and to operate electrocardiographic equipment. The technician who assisted in this study is certified by the National Alliance of Cardiovascular Technologists, Cardiovascular Credentials International, and the National Society of Cardiovascular Technologists. Certification requirements vary from one institution to another, but usually require a knowledge of the electrophysiology of the heart, and the ability to identify arrhythmias of a given complexity with 100% accuracy.

The ECGs obtained from the Holter tapes were transcribed with an Applied Cardiac Systems Holter Reporter computer program. ECG rhythm strips were printed for both the rest period and the etude playing time for each subject who participated in the first phase of the study. For the second research problem, rhythm strips were printed for each of the following situations: the 15 minute rest period, the practice period, the performance,
and the half hour following the performance. Additional rhythm strips were printed for any irregularities beyond those included in these strips, and for the activity between these specified situations. The minute by minute heart rates, hourly summaries and the Tabulator Summary Report, which compiles all of the heart rate and rhythm data, were included. An initial assessment of the nature of any arrhythmias found was made by the ECG technician.

Using the compiled ECG records, the Holter Reports, and medical profiles, a cardiologist analyzed the heart rate response, any arrhythmias and their temporal relationship to the individuals' activities; and any other electrocardiographic changes suggesting possible underlying cardiac disease. When further testing or information was needed, the subject was notified and given the opportunity to continue in the study.

Statistical Analysis

The statistical calculations in the study were performed with the Statistics With Finesse computer program. A dependent t test was performed to determine whether a significant difference existed between the playing and resting heart rates.
CHAPTER IV

RESULTS

The purpose of this study was to investigate the effects of trumpet playing upon the heart. The problems of the study were as follows:

1. To determine whether there is a significant increase in heart rate during trumpet playing.

2. To compare the heart’s response in two settings: individual practice and a performance.

3. To identify any changes in heart rhythm which occur during trumpet playing.

A Holter monitor was used to record electrocardiograms (ECGs) to examine the heart’s response during trumpet playing. The use of this small, portable recorder made it possible to collect data in practice sessions and live performances. The Holter tapes were transcribed and printed in standard ECG format with an Applied Cardiac Systems computer program. Each subject also completed a medical questionnaire prior to testing. The ECG and medical profile of each subject was examined and evaluated by a cardiologist and an ECG technician.

To investigate the first problem, twenty-one subjects were given an electrocardiograph test at rest and while playing a standard selection of music. After a rest period of 15 minutes, the subjects played the supplied etude, using a metronome to standardize the tempo and duration. After playing the standard etude, the subjects were invited to play any other music of their
choice. A few trumpet players took the opportunity to experiment with extremes of range, dynamic volume, or demanding passages in the trumpet literature. When determining the playing heart rate for the first research question, however, only data from the standard etude was used in comparison with the resting heart rate. The maximum heart rate was determined from the six second interval with the fastest rate in each of the two situations. Table 3 shows the maximum heart rate recorded during rest and instrument playing for each subject.

Table 3

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Etude</th>
</tr>
</thead>
<tbody>
<tr>
<td># 1</td>
<td>93</td>
<td>115</td>
</tr>
<tr>
<td># 2</td>
<td>107</td>
<td>118</td>
</tr>
<tr>
<td># 3</td>
<td>76</td>
<td>115</td>
</tr>
<tr>
<td># 4</td>
<td>102</td>
<td>118</td>
</tr>
<tr>
<td># 5</td>
<td>90</td>
<td>118</td>
</tr>
<tr>
<td># 6</td>
<td>86</td>
<td>146</td>
</tr>
<tr>
<td># 7</td>
<td>104</td>
<td>115</td>
</tr>
<tr>
<td># 8</td>
<td>67</td>
<td>100</td>
</tr>
<tr>
<td># 9</td>
<td>113</td>
<td>146</td>
</tr>
<tr>
<td>#10</td>
<td>81</td>
<td>107</td>
</tr>
<tr>
<td>#11</td>
<td>85</td>
<td>107</td>
</tr>
<tr>
<td>#12</td>
<td>78</td>
<td>115</td>
</tr>
<tr>
<td>#13</td>
<td>88</td>
<td>98</td>
</tr>
<tr>
<td>#14</td>
<td>90</td>
<td>118</td>
</tr>
<tr>
<td>#15</td>
<td>88</td>
<td>111</td>
</tr>
<tr>
<td>#16</td>
<td>75</td>
<td>98</td>
</tr>
<tr>
<td>#17</td>
<td>100</td>
<td>115</td>
</tr>
<tr>
<td>#18</td>
<td>102</td>
<td>150</td>
</tr>
<tr>
<td>#19</td>
<td>87</td>
<td>111</td>
</tr>
<tr>
<td>#20</td>
<td>105</td>
<td>136</td>
</tr>
<tr>
<td>#21</td>
<td>119</td>
<td>136</td>
</tr>
</tbody>
</table>

A dependent *t* test was used to determine whether a significant difference existed between the playing and resting heart rates. As shown in Table 4, the mean heart rate for all subjects when resting was 92 beats per minute (bpm), while the mean heart rate during etude playing was 119 bpm. As expected, each subject experienced an increase in heart rate while playing the music; the mean heart rate for all subjects while playing was significantly higher (*p* < .0001) than when resting.
The second research problem examined cardiovascular stress in performances and practice sessions. The heart's response in these two situations is described in terms of mean heart rate, and the severity of instances of the Valsalva maneuver. As discussed in Chapter Two, the Valsalva maneuver, which can be caused by blowing against fixed resistance, results in a distinctive cycle of irregular heart rhythm.

Twelve subjects participated in this phase of the study. Each selected one or more pieces of music to be played during a practice session and a public performance. The ECG recording process was similar to that previously described, with further recording during the daily activities of the subject. An activity log was used to show the time of each event during the recording period. Each ECG recording was at least three hours in

### Table 4

**t Test for Dependent Measures**

<table>
<thead>
<tr>
<th>Item</th>
<th>Resting</th>
<th>Playing</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Mean</td>
<td>92.19</td>
<td>119.05</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>13.43</td>
<td>15.45</td>
</tr>
<tr>
<td>Difference in Means</td>
<td>26.86</td>
<td></td>
</tr>
<tr>
<td>t Value</td>
<td>10.1397</td>
<td></td>
</tr>
<tr>
<td>Probability One-Tailed</td>
<td>.0001</td>
<td></td>
</tr>
</tbody>
</table>

The second research problem examined cardiovascular stress in performances and practice sessions. The heart's response in these two situations is described in terms of mean heart rate, and the severity of instances of the Valsalva maneuver. As discussed in Chapter Two, the Valsalva maneuver, which can be caused by blowing against fixed resistance, results in a distinctive cycle of irregular heart rhythm.

Twelve subjects participated in this phase of the study. Each selected one or more pieces of music to be played during a practice session and a public performance. The ECG recording process was similar to that previously described, with further recording during the daily activities of the subject. An activity log was used to show the time of each event during the recording period. Each ECG recording was at least three hours in
duration and included an initial resting period, a practice session, a
performance, and other activities of the subject's daily routine.

The mean heart rate during performance was calculated by using the
Applied Cardiac Systems minute by minute tabulation of heart rate,
averaging the figures for the periods in which the subject was playing. This
calculation did not include extended periods in which no playing occurred,
such as the intermission of a concert. The mean heart rate during practice
was determined in the same manner, averaging the minute by minute heart
rate during the time the concert piece or pieces were being played straight
through. Table 5 shows the mean heart rate during practice and performance
and the percent increase experienced by each subject.

Table 5

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mean HR Practice</th>
<th>Mean HR Performance</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>94</td>
<td>98</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>128</td>
<td>150</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>94</td>
<td>110</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>87</td>
<td>99</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>99</td>
<td>101</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>81</td>
<td>99</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>NA</td>
<td>126</td>
<td>NA</td>
</tr>
<tr>
<td>8</td>
<td>74</td>
<td>170</td>
<td>129</td>
</tr>
<tr>
<td>9</td>
<td>NA</td>
<td>133</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>NA</td>
<td>109</td>
<td>NA</td>
</tr>
<tr>
<td>11</td>
<td>96</td>
<td>92</td>
<td>-4</td>
</tr>
<tr>
<td>12</td>
<td>102</td>
<td>113</td>
<td>10</td>
</tr>
</tbody>
</table>

Note. NA = not available.

Nine of the subjects completed this phase of the study exactly as directed,
practicing straight through the piece or pieces which were later performed.
The other three subjects either did not practice the same music during the monitoring period, or did not do so in a manner which would allow an accurate comparison between the rehearsal and the performance. Eight of the nine subjects experienced a faster heart rate during performance than in practice; one subject had a slightly slower rate while performing.

In addition to the mean heart rate, the second aspect of heart response compared in practice and performance was the intensity of the Valsalva maneuver. All subjects participating in this phase of the study produced the irregular rhythm characteristic of the Valsalva maneuver while playing the trumpet. Instances of sinus arrhythmia were classified as mild when adjacent cycle lengths varied from 10 to 24%; moderate sinus arrhythmia was defined as variations of 25 to 49%; variations of 50% or more were classified as marked sinus arrhythmia. The most severe disturbance was reported in each situation.

Table 6

<table>
<thead>
<tr>
<th>Subject</th>
<th>Practice</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>2</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>3</td>
<td>marked</td>
<td>marked</td>
</tr>
<tr>
<td>4</td>
<td>marked</td>
<td>marked</td>
</tr>
<tr>
<td>5</td>
<td>mild</td>
<td>mild</td>
</tr>
<tr>
<td>6</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>7</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>8</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>9</td>
<td>NA</td>
<td>marked</td>
</tr>
<tr>
<td>10</td>
<td>moderate</td>
<td>marked</td>
</tr>
<tr>
<td>11</td>
<td>moderate</td>
<td>moderate</td>
</tr>
<tr>
<td>12</td>
<td>mild</td>
<td>moderate</td>
</tr>
</tbody>
</table>

Note. NA = not available.
One subject did not participate in a practice session. Of the eleven subjects who were monitored during both settings, only two subjects exhibited a more pronounced cycle of sinus arrhythmia in performance than in practice.

As discussed in Chapter Two, the Valsalva maneuver observed in brass players is related to the air pressures used to play the instrument. The severity of the rhythm changes seen in the ECG shows the effect that these air pressures have upon the heart. The intensity of the Valsalva maneuver did not seem to be affected by the playing situation to the same extent that the heart rate was affected in different settings.

For the third research problem, specific arrhythmias occurring during trumpet playing were identified. The ECG tapes from all subjects were examined for arrhythmias occurring during any of the playing situations, including the standard selection of music and any other playing done in the test for the first research problem, and the practice session and performance recordings obtained for the second problem.

The arrhythmias found in this study include those previously reported in brass players (Tucker, Faulkner, & Horvath, 1971), such as premature atrial contractions (PAC), premature ventricular contractions (PVC), and the Valsalva maneuver. In addition, three subjects in the present study exhibited an escape mechanism during the Valsalva maneuver while playing the trumpet. As described in Chapter Two, escape beats occur when the electrical impulse which causes the heart to contract is suppressed at the sinus node, allowing another area of the heart to initiate a beat.

One of the three subjects produced a ventricular escape beat (Figure 11), while another had an escape beat originating in the atroventricular
junction (Figure 12). The third subject had a junctional escape rhythm, in which the atrio-ventricular junction assumes the pacemaking function for a period of time.

Figure 11. Ventricular Escape Beat

Figure 12. Junctional Escape Beat
Several subjects exhibited arrhythmias that could be attributed to the physiological condition of the subject. One subject experienced severe rhythmic disturbances at rest and during trumpet playing (Figure 13). These disturbances included sustained sinus tachycardia and supraventricular tachycardia of over 200 beats per minute at rest, complex ventricular arrhythmias, and inverted T waves. This subject was advised of the abnormal test results, and was referred to a physician for further examination.

Figure 13. Complex Arrhythmias

Seven subjects were found to have a right bundle branch block (BBB), a condition in which the impulse causing the heart to beat is delayed in the conductive pathway on the right side of the heart. This delay causes the QRS complex to be wider than normal, because the impulse takes longer to travel through the heart. In one of the subjects, this intraventricular conduction delay was present throughout the ECG recording period, but increased during
trumpet playing. A second subject had an incomplete right bundle branch
delay during a practice session, but a normal ECG during a concert. In the
other five subjects, the delay was present throughout the test, and was
unaffected by trumpet playing.

One 18 year old subject experienced many premature heart beats before,
during, and after trumpet playing. About 80% were ventricular (PVCs),
and the remainder were PACs. There were approximately three premature
beats per minute throughout the ECG test. The frequency of the premature
beats did not change during the periods of trumpet playing. The numerous
PVCs were attributed to myocardial irritability. Such irritability is not
necessarily abnormal in young adults.

As expected, all of the 24 subjects produced the Valsalva maneuver
during trumpet playing. Eleven of the subjects exhibited other arrhythmias
during the recording period. Table 7 shows the number of subjects who
experienced each type of arrhythmia in the study. The categories are not
mutually exclusive; for example, one subject had premature atrial and
ventricular contractions and a ventricular escape beat in addition to the
Valsalva maneuver.

Table 7

<table>
<thead>
<tr>
<th>Arrhythmias Produced During Trumpet Playing</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 24</td>
</tr>
<tr>
<td>Val. PVC PAC Escape BBB</td>
</tr>
<tr>
<td>n = 24 8 8 3 7</td>
</tr>
</tbody>
</table>
In addition to the arrhythmias listed above, one subject exhibited a short burst of atrial tachycardia, a three beat run of PACs. Another subject had a run of ventricular tachycardia, a very fast rhythm caused when a site in the ventricles becomes irritable and overrides the sinus node to produce a ventricular rhythm. The interpretation of each subject’s ECG made by the cardiologist and technician is found in Appendix B.

Of the eleven subjects who were monitored in both practice and performance situations, three exhibited no arrhythmias other than the Valsalva maneuver. A comparison between the practice and performance situations of the remaining eight subjects showed that more irregular rhythms occurred during performances. All of the escape mechanisms occurred during performances, as did the instances of atrial tachycardia and ventricular tachycardia.

In addition, the premature beats were more prevalent in performance situations. Four subjects had a total of seven PVCs during practice situations, while 23 PVCs occurred during their performances. Likewise, each individual exhibiting the PVCs had more during the performance than in the rehearsal. Six of the eight subjects had a total of four PACs during practice, and eight PACs during performances. However, two of these six subjects had one PAC each during practice, and no PACs while performing.
CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to investigate the effects of trumpet playing upon the heart. A small, inconspicuous heart monitor was used to record electrocardiograms (ECGs) during live musical performances and practice sessions. The problems of the study were as follows:

1. To determine whether there was a significant increase in heart rate during trumpet playing.

2. To compare the heart’s response in two settings: individual practice and a performance.

3. To identify the changes in heart rhythm which occurred during trumpet playing.

A total of 24 trumpet players volunteered for this study. A wide range of abilities was represented, from high school students to professional performers. Members of various types of ensembles including rock bands, brass quintets, and professional and community orchestras, participated in the study. The subjects were between 18 and 43 years of age.

Gates et al. (1985) attributed an increase in heart rate among singers to the physical activity of singing. Bouhuys (1964, 1966) found that wind instrument playing made greater demands on the cardiopulmonary system than did singing. Furthermore, the trumpet was found to be the most demanding in a comparison among wind instruments (Bouhuys 1964). The present study examined the heart’s activity during trumpet playing.
For the first research problem, 21 subjects were monitored at rest and while playing a standard etude. The maximum heart rate during these situations was determined for each subject and the results compared by means of a dependent t test. The heart rate during trumpet playing was found to be significantly higher ($p < .0001$) than when resting.

The second research problem compared the heart's response in practice and performance situations. Twelve subjects participated in this phase of the study. Each chose one or more pieces of music to play while being monitored in both situations. The two aspects of heart response which were examined in this problem were the heart rate, and the occurrence and severity of the Valsalva maneuver.

In addition to indicating the amount of work being performed, the heart rate can reveal the added stress of a situation. Many musicians feel that the stress of playing an instrument is increased during performance situations. This heightened physiological arousal was noted in both anxious and non-anxious performers (Craske & Craig, 1984). Several studies have recorded heart rate as an objective, physical measure of the stress experienced by the performer. The present study is one of a few to use continuous monitoring during live performance and practice to examine the physical requirements of playing an instrument, as well as the added stress upon the heart in a performance.

The mean heart rate during practice was calculated for the period of time that the music was played straight through; this was compared to the mean heart rate during a public performance of the same music. Eight of the nine subjects completing the heart rate comparison experienced a faster heart rate
during the performance. One subject had a slight decrease in heart rate while performing.

For this group of subjects, the average increase in heart rate was 23%. The greatest rate change was from 74 beats per minute (bpm) in practice to 170 bpm in performance, an increase of 129%. This occurred during a performance of the Del Borgo Trumpet Sonata. Although this subject followed the general pattern reported by Neftel et al. (1982), experiencing an increase in heart rate during the last ninety seconds before beginning the performance, he sustained an extremely rapid heart rate averaging 139 bpm from 20 minutes before the performance until 30 minutes after the last note. The only subject who had a slower heart rate in performance was playing third trumpet in a jazz band concert.

The second aspect of heart response examined in this comparison was the intensity of the Valsalva maneuver produced during trumpet playing. The Valsalva maneuver causes a characteristic pattern of irregular heart rate: the heart rate decreases suddenly, and then gradually increases to its previous rate or faster. Instances of the Valsalva maneuver were classified as mild, moderate, or marked, based on the percentage of rate change between the adjacent heart beats. Eleven subjects were involved in this comparison of the heart's rhythmic response. Two subjects had a more pronounced disturbance in heart rhythm during performance than in practice; the other nine had the same classification of rhythm change in both situations.

The Valsalva maneuver is a physiologic mechanism which occurs in response to the internal straining which occurs during trumpet playing. The results of this study indicate that the degree of air compression noted in
practice can increase during performance situations, but that most of the subjects performed without any increase in this strain. In contrast, the majority of trumpet players did experience an increase in heart rate on stage, indicating the arousal of the autonomic nervous system during performances. Thus, during performances, the heart rate usually increases as a result of the body's response to the situation, while the physical effort needed to play the same music is unchanged, although the subjects may increase their voluntary efforts unnecessarily.

The third research problem identified the arrhythmias which occurred during trumpet playing. A cardiologist and an ECG technician evaluated the ECGs, examining the heart rate response, and any arrhythmias and their relationship to trumpet playing. In order to determine whether the ECG changes were a function of the instrument playing or were attributable to the physiological condition of the subject himself, additional ECG data from post-playing times, rest periods, and other activities of the subject were examined along with the medical profile information in the evaluation of each subject. Using this information, the medical professionals characterized the nature of arrhythmias as induced by the instrument playing, or as caused by other means.

Arrhythmias which occurred only during trumpet playing, did not persist after playing, and were not accompanied by other symptoms or medical indications of physiological abnormalities were attributed to the instrument playing. For example, all subjects experienced episodes of the Valsalva maneuver during trumpet playing, which was determined to be an induced arrhythmia in these cases. Other arrhythmias which were induced
by trumpet playing included premature atrial and ventricular contractions, atrial tachycardia, and ventricular and junctional escape beats.

Nine subjects exhibited arrhythmias attributed to physiological causes. One subject experienced severe rhythmic disturbances which were unrelated to trumpet playing. Another had frequent premature contractions throughout the test. In addition, seven trumpet players experienced a right bundle branch block during the monitoring period.

Discussion

This investigation confirmed a significant increase in heart rate during trumpet playing, showing the physical demands of playing the instrument. This finding was consistent for all of the subjects involved, and probably could be replicated.

In a comparison of practice and performance situations, the majority of trumpet players (89%) experienced an increase in heart rate on stage. Instances of the Valsalva Maneuver, on the other hand, were more pronounced in only 18% of the performances. Therefore, the added stress of a performance situation had a significant effect on the heart rate, while the severity of the Valsalva maneuver was determined mainly by the requirements of the music and the efficiency of the player.

The greatest increase in heart rate occurred during a performance of a trumpet Sonata. Although this study did not address this issue, the preliminary conclusion that more stress upon the heart can be expected during solo performances than in ensemble concerts is in accordance with the findings of performance anxiety studies.
The extended ECG recording made it possible to obtain additional information about heart response while performing. Analysis of the ECGs showed that in addition to the faster rate, there was a general pattern of more irregularities in the heart rhythm during performances. Although both the heart rate and rhythm of trumpet players were affected during performances, none of these changes persisted after playing.

In addition to the above findings, the ECGs were examined for evidence of a cumulative increase in stress upon the heart during practice. A previous study (Tucker, Faulkner, and Horvath, 1971) suggested this possibility after having subjects repeat an etude as many times as possible without stopping, until fatigued. The authors reported more ECG changes occurring at the end of these sessions than at the beginning.

The practice sessions in the present study differed from those in the Tucker study (1971) in that the subjects were instructed to use their daily warm up or any established routines, and continue to practice in their normal manner. A comparison of the first and last five minutes of the ECGs recorded in practice sessions showed little change in either heart rate or number of arrhythmias occurring. Although this comparison was not part of the research design, observations appear to indicate that in routine practice sessions, the trumpet players seemed to pace themselves, and did not make excessive demands upon the heart. The ECGs of these practice sessions, which lasted from 20 minutes to 90 minutes, did not exhibit any type of cumulative effect in the heart response.

It should be pointed out that the 24 subjects were volunteers, and half of them participated in the live performance phase of the study. As noted in the performance anxiety literature (Wolfe, 1989), people who are most affected
by the physical manifestations of stage fright are likely to avoid such situations. This is a possible explanation for the number of trumpet players who agreed to participate in the etude playing session, but were unwilling to be monitored in a live performance.

Therefore, because the participants in the performance phase of the study may not be representative of all trumpet players, the results of the practice and performance comparison cannot be extrapolated to the entire population of trumpet players. The general pattern of increased heart response in performances, however, has been reported in numerous studies of singers and instrumentalists.

When monitored in conventional practice sessions and actual performances, trumpet players in this study exhibited various cardiac arrhythmias. Previous studies had reported ECG changes in up to 93% of brass players (Borgia et al., 1975; Tucker, Faulkner, & Horvath, 1971), but in some cases were produced under extreme and unrealistic conditions. The present study confirmed the occurrence of these ECG changes in some subjects. Thirteen of the twenty-four participants, however, had no arrhythmias other than the heart rate change characteristic of the Valsalva maneuver. The remaining eleven subjects experienced arrhythmias similar to those reported in healthy athletes (Pantano & Oriel, 1982).

In order to put the findings of the present study in perspective, it is important to examine the implications of these other arrhythmias as well as to determine the conditions in which they occur. The presence of arrhythmias may be an indicator of a serious condition, or simply a normal response to a
temporary situation or activity. The ECG findings must be interpreted in the context of the subject's daily activities and medical history.

A cardiologist and an ECG technician analyzed the ECGs and assessed the significance of the changes found. Although several types of arrhythmias were induced during trumpet playing, none of these ECG changes persisted, and there were no signs of adaptive changes in the heart itself, as was suggested in a previous study (Borgia et al., 1975). After examining the ECGs of the 24 subjects, the medical professionals concluded that the data presented no evidence of any adverse effect of trumpet playing on the cardiovascular system. In the absence of other symptoms, these ECG changes can be considered normal variants which occur as a function of instrument playing.

Recommendations for Further Study

This study was designed to investigate the effects of trumpet playing upon the heart, and to assess the clinical significance of the findings. Although the research questions of this study were designed to gather data on heart rate and rhythm changes during practice and performance situations, the additional information obtained presented some patterns which might warrant further investigation.

Borgia et al. (1975) found more arrhythmias in female horn players than in their male counterparts. The authors suggested that the smaller lung volumes of the female musicians might require them to use more effort than males, triggering greater internal responses. The present study included three female trumpet players; all three were monitored while playing the standard etude, and one continued in the practice and performance comparison. The only arrhythmias observed for the three females during the etude playing
were mild instances of the Valsalva maneuver. The extended monitoring of one female trumpet player revealed similar, mild Valsalva changes in practice, which increased to moderate changes during performance. No other arrhythmias were observed in this subject.

With the exception of the Valsalva maneuver, which was produced by all 24 subjects, the only arrhythmias reported in this study were observed in 11 male trumpet players. Although this does not coincide with the findings of Borgia et al. (1975), additional study should examine larger groups of male and female trumpet players before conclusions can be drawn about their relative susceptibility to arrhythmias during trumpet playing.

An additional area of study might examine whether increased physical activity during instrument playing would affect the heart’s rhythmic response as well as its rate. Subjects in the present investigation performed in various settings such as orchestras, stage bands, solo performances, and brass quintets. Bouhuys (1964) studied the energy expended in wind instrument players, pointing out that greater physiological effort would be required from members of marching bands. Because physical exercise has a decided effect on the circulatory system, marching band directors may be aided by research in this area.

The present study involved trumpet players from a wide range of backgrounds and ability levels. Brantigan, Brantigan, and Joseph (1982) reported finding more cardiovascular stress in professional musicians than in college music students. Steptoe (1989) suggested that the nature of an orchestral playing job may produce stress on the heart, in addition to the physiological responses occurring in performances. Steptoe characterized an orchestral position in terms of a "demand-control" model developed by Karasek
Karasek's research showed that jobs which involve high demand combined with little control in decision making carry a higher risk of ischaemic heart disease. Steptoe noted that the symphony musician fits this description. Orchestra members must have highly refined skills, yet they have little autonomy on the job. Haider and Groll-Knapp (1981) found evidence of temporary circulatory stress in professional orchestral players during rehearsals and performances of the Vienna Symphony. Future research might use a longitudinal design to examine occupational stress factors in orchestral players.
APPENDIX A

Information and Consent Forms
Subject Consent Form

Name

Phone

I agree to participate in a research project investigating the effects of brass instrument playing upon heart function. I understand that I will be given an electrocardiograph test while playing my instrument in different situations, including individual practice, and a performance. I realize that there is minimal risk involved with this project, and that I may refuse to participate, or withdraw from the study at any time, without penalty. I understand that my identity will be kept confidential.

Signed ___________________________ Date ___________________________

This project has been approved by the University of North Texas Institutional Review Board.
Medical Profile

Name

Age  Weight  Height

Medications

1. Are you a ___ Smoker  ___ Non smoker

2. Diabetic ___ Yes  ___ No

3. Have any of your immediate relatives (parents, brothers, or sisters) had a heart attack or other heart problems? ___ Yes  ___ No
   If so, list relationship

4. Have you ever had a heart attack or any other heart problems?
   ___ Yes  ___ No
   If so, please describe

5. Please indicate any of the following symptoms you have felt during or shortly after trumpet playing
   ___ Chest pain
   ___ Black out
   ___ Pounding heart
   ___ Dizziness

6. Which of the following have you used in the last 12 hours?
   ___ Cigarettes  ___ Caffine
   ___ Alcohol
   ___ Any other medicines
   ___ Beta Blockers

This project has been approved by the University of North Texas Institutional Review Board.
Instructions for monitor hook-up and electrode attachment are found on the back of the activity log.

After monitor hook-up:

1. Write your name on the cassette tape.
2. Flip the power switch down to the "On" position. This switch is located next to the battery.
3. Hold down the black button labelled "event marker" for 15 seconds, then release.
4. Check the clock on the monitor and record the time and the word "start" on the first line of the activity log.

The machine is now recording. Wait at least 20 minutes before playing your instrument or starting any strenuous activity; this will provide a baseline ECG for later comparison.

5. After this 20 minute time period, record the time and description of each activity.
   A. During instrument practice, follow your normal routine, and practice in your usual manner.
   B. Keep a detailed record of the material you play; include a short description, or the name of each piece. Indicate the piece or pieces you will be performing later.
   C. During your performance, have someone else record the time that you start and finish playing, if necessary.
   D. The log should include any other activities you engage in between or after playing sessions.

6. Wait at least 30 minutes after the performance ends; turn the monitor off.
APPENDIX B

ECG ANALYSES
Subject 1

Normal sinus rhythm was present throughout the time of observation. Rate varies from 75 beats per minute to 118 beats per minute during baseline ECG. Sinus arrhythmia is present at 07:17:00.

Practice: Sinus rate varies from 85 to 95 beats per minute. Sinus tachycardia with rate of 120 is present at 07:13:27. One isolated premature ventricular contraction is seen at 07:30:59.

Practice (rehearsal): Sinus tachycardia 138 beats per minute slowing to 66 beats per minute, 07:42:45. Isolated PVC at 08:11:10.

Interim: Normal sinus rhythm with rates of 80 to 90 beats per minute.

Performance I: Sinus tachycardia up to 148 beats per minute, 08:39:27 occurred. Occasional premature atrial contractions 08:36:11, 08:58:26, 08:58:34, was recorded. Isolated PVCs are also seen 08:58:42, 09:02:17.

Interim following Performance: One premature ventricular contraction occurs at 09:45:56.

Subject 2

**Baseline ECG:** Normal sinus rhythm at rates of 80 to 90 beats per minute.

**Practice:** One premature ventricular contraction occurs at 08:16:35.

**Practice (rehearsal):** Rate increases up to 150 beats per minute. One premature atrial contraction at 08:24:35.

**Performance I:** Infrequent PVCs are seen 08:32:07, 08:35:15. Sinus tachycardia up to 140 beats per minute.

**Performance II:** Occasional PVCs, 09:55:46, 10:05:18. Sinus tachycardia up to 140 beats per minute.

**Post Playing Period:** Rate slows to 92 beats per minute.

**Etude:** Excerpt 1 has a Valsalva effect at 08:48:09, with sinus tachycardia 135 beats per minute followed by transient slowing to 54 beats per minute. Sinus rate is 120 beats per minute during Excerpt 1. During Excerpts 2 and 3, rate varies from 90 to 100 beats per minute.
Subject 3

Baseline ECG: Rate varies from 95 to 125 beats per minute. One premature ventricular contraction at 21:11:45.

Practice: Valsalva effect with sinus tachycardia 130, slowing to 70 beats per minute, 21:43:32.

Performance: Valsalva effect with rate increasing to 138 beats per minute followed by sudden slowing 1.5 seconds at 22:02:18. Rate is up to 150 beats per minute during performance. A second Valsalva effect at 22:49:08 is present with 1.4 second pause at the end of Valsalva maneuver.

Practice (rehearsal): Unremarkable other than for sinus arrhythmia. Isolated premature atrial contraction with aberration at 11:14:54 during performance. Minor Valsalva effects at 11:30:03, 11:35:09. At 11:38:50, a Valsalva effect with rate up to 123 beats per minute followed by AV junctional escape beat.

Etude: Excerpt 1 is unremarkable. Excerpt 2 has sinus tachycardia with mild Valsalva maneuver 128 slowing to 68 beats per minute at 12:11:09.
Subject 4

**Baseline ECG:** Sinus rhythm, right bundle branch block intraventricular conduction delay is present.

**Practice:** Minor Valsalva effect at 10:10:30, 10:31:55, and 10:56:40.

**Practice (rehearsal):** Rate increases up to 110 beats with 1.4 second pause, followed by transient junctional escape rhythm. Minor Valsalva effect seen is seen with piccolo trumpet at 11:34:50.

**Performance:** Minor Valsalva also seen during performance at 13:20:08.

**Etude:** Rates vary from 75 to 85 beats per minute during the three excerpts.
Subject 5

**Baseline ECG:** Rate is 95 to 110 beats per minute.

**Practice:** No major changes during practice. Incomplete right bundle branch block was present.

**Etude:** Sinus arrhythmia with rates from 80 to 90 beats per minute during Excerpts 1, 2, and 3.

**Performance:** Rates varied from 75 to 110 per minute. Some slight ST elevation is seen during performance which is early repolarization, a normal variant. Rate is about 90 after concert.
Subject 6

Resting heart rate is 75 beats per minute. Rate increases up to 90 beats per minute during Excerpt 1. A Valsalva effect at 10:27:58. Rate increases to 128 bpm during Excerpt 2. Another Valsalva effect at 10:30:10.
Subject 7

During Excerpt 1, an isolated premature ventricular contraction was seen. During Excerpt 2, rate increased up to 130 beats per minute from a baseline of 95 beats per minute at rest. Isolated PVCs were seen during Excerpts 2 and 3. Valsalva effects were seen at 13:55:42 and 13:57:39.
Subject 8

Premature atrial contractions with aberration were present during rest and Excerpt 1. Frequent PACs were seen during Excerpts 2 and 3 as well as during the post playing period. No significant rate changes occurred.
Subject 9

Minor Valsalva effect is seen in Etude. No arrhythmias, no tachycardias occurred otherwise.

Minor ST elevation is seen, which is a normal variant (early repolarization).
Subject 10

Rate increases from 90 beats per minute at rest to up to 115 beats per minute during Etude. No other changes are identified.
Subject 11

Rehearsal: Occasional premature ventricular contraction is seen during practice of Bizet [L'Arlesienne Suite No. 1] and Shostakovich [Festive Overture], but not with Beethoven [Egmont Overture]. No significant changes were seen with piccolo trumpet playing.

Performance: Valsalva effect with rate increasing to 135 and slowing to 90 beats per minute at 20:18:14. Occasional PVCs during performance of Shostakovich only.

Etudes: Minor Valsalva effect is seen.
Subject 12

**Baseline ECG:** Sinus rhythm with rate of 70 to 90 beats per minute is present.

**Practice:** Rate increases to 120 beats per minute during practice with occasional PVC, 10:17:05, and occasional PAC, 10:34:18. A Valsalva effect followed by a ventricular escape beat is present at 10:37:49. A minor Valsalva effect is also seen at 10:43:30, Isolated PACs are recorded at 10:43:38 and 11:58:51.

**Performance:** One three beat salvo of atrial tachycardia occurs during warm up at 19:59:31. Premature atrial contractions occur at 19:59:31, and PVCs occur at 20:14:00. Rate increases up to 163 beats per minute at 20:15:08, during performance.
Subject 13

Baseline ECG: Sinus arrhythmia at rates of 58 to 85 beats per minute is present at rest.

Etude: Minor Valsalva effect occurs during etude. Sinus arrhythmia occurs during all three excerpts.
Subject 14

**Baseline ECG:** Sinus arrhythmia at rates of 80 beats per minute is present during rest.

**Etude:** Rate slows to 58 beats per minute during Excerpt 2 and increases to 100 beats per minute during Excerpt 3.
Subject 15

**Baseline ECG:** Rate is 85 beats per minute at rest.

**Etude:** Rate is 63 beats per minute during Excerpt 1, up to 95 bpm during Excerpt 2, and 72 bpm during Excerpt 3.

**Practice:** No significant changes seen during piccolo trumpet playing.
Subject 16

**Baseline ECG:** Right bundle branch block is present. Rate varies from 72 to 90 beats per minute during rest.

**Etude:** No major rate change occurred during Excerpt 1. Rate increased up to 118 bpm during Excerpt 2. Sinus arrhythmia is seen during Excerpt 3.
Subject 17

**Baseline ECG:** Right bundle branch block pattern. Sinus arrhythmia with rates from 75 to 90 beats per minute is present at rest.

**Etude:** Isolated PVCs occur during Excerpts 1 and 2. Rate increases up to 120 beats per minute during Excerpt 3.
Subject 18

**Baseline ECG:** Right bundle branch block. Sinus rate varies from 58 to 62 beats per minute during rest.

**Etude:** An isolated premature atrial contraction is seen during Excerpt 1 at 20:35:30. A minor Valsalva effect is seen during Excerpt 3 at 20:40:38, somewhat more pronounced at 20:41:14.

**Rehearsal:** Rate increases to 100 beats per minute during practice of Mvt. I [Del Borgo Trumpet Sonata], and 118 bpm during Mvt. II.

**Performance:** The subject has paroxysmal atrial ventricular tachycardia at rest and during performance, and then converts to sinus rhythm in the post-playing period at 12:25:50.
Subject 19

Subject 20

**Baseline ECG:** Rate is about 80 beats per minute at rest. An isolated premature atrial contraction is seen during warm up at 19:12:27.

**Etude:** Rate and rhythm during etude are unremarkable.
Subject 21

Baseline ECG: Incomplete right bundle branch block is present throughout time of monitoring. Rate varies from 100 to 132 beats per minute.

Etude: A Valsalva effect is seen in Excerpt 1 at 13:21:11. Rate increases up to 150 beats per minute during Excerpt 2, and a minor Valsalva effect is seen. Rate is also about 150 beats per minute during Excerpt 3.
Subject 22

**Baseline ECG:** Right bundle branch block is present throughout. Rate varies from 80 to 95 beats per minute at rest.

**Etude:** Rate increases to 118 beats per minute during Excerpt 1. A minor Valsalva effect is seen during Excerpt 3, at 17:19:25. A minor Valsalva effect at 17:16:06 during Excerpt 2.

**Practice:** Another Valsalva effect at 19:38:20; more marked effect than previously.

**Performance:** Isolated PAC is seen during performance as well as a Valsalva change at 21:48:22. Rate increases up to 135 beats per minute during performance.
Subject 23

**Baseline ECG:** Sinus rhythm is present at rates of 90 to 100 beats per minute during rest.

**Étude:** A Valsalva effect is seen during Excerpt 2. Rate varies from 85 to 150 bpm during Excerpt 3.

**Performance:** Rate increases up to 125 beats per minute during performance at 21:08:10.
Subject 24

**Baseline ECG:** Rates vary from 95 to 110 beats per minute at rest.

**Performance:** Rate is 125 beats per minute at beginning of performance, increasing to 145 bpm at 12:00:31. A Valsalva effect is seen at 12:02:16.

**Etude:** Rate during Excerpt 1 is 115 beats per minute; during Excerpt 2, rate increases to 128 bpm. Rate is 135 bpm during Excerpt 3.
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