AN ANALYSIS OF SELECTED RESPIRATORY AND CARDIOVASCULAR CHARACTERISTICS OF WIND INSTRUMENT PERFORMERS

Presented by

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THESIS ABSTRACT

Little objective information on wind instrument performance physiology is available or accessible to musicians. Research on wind instrument performance physiology includes: measurements of specific airflow pressures while playing wind instruments, measurements of lung volumes and capacities, and electrocardiograms taken during wind instrument performance.

The purpose of this study was to examine selected respiratory and cardiovascular responses of wind instrumentalists and non-wind instrumentalists at the Eastman School of Music. Lung volumes, breathing patterns at rest, maximal airway pressures, peak flow rates, and pulse rate responses to thirty-second breath holds at increased airway pressures were determined. Equipment included a Wright Peak Flow Meter, a six-liter fast-recording spirometer, a six-liter recording respirometer, a photoelectric finger plethysmograph, a water manometer, and a polygraph.

The data indicated that: 1) Wind instrumentalists do not have greater vital capacities than predicted for their sex, height, and age; therefore, assumptions that wind instrumentalists need large vital capacities, and that wind instrument performance changes vital capacity are irrelevant to successful wind instrument performance. 2) At rest, some wind instrumentalists may breathe slightly slower, but not deeper, than controls. These results support results of earlier studies. 3) Male and female wind instrumentalists are able to produce significantly greater maximal airway

pressures than controls, indicating a possible adaptation in the strength of respiratory muscles. This strength may be related to the demands of wind instrument performance. 4) Pulse rate responses of wind players and controls do not differ from each other significantly before, during, and after a thirty-second breath hold producing airway pressure of 40 cm H_2O. However, there is a significant difference in pulse rate responses of males when compared with those of females. Pulse rate of the female does not vary as greatly as the pulse rate of the male.

DEDICATION

Dedicated with love to my mother and father

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CHAPTER I

INTRODUCTION

THE PURPOSE OF THIS STUDY

This study compares selected physiologic responses of wind instrumentalists and other musicians who do not play wind instruments. Subjects included women as well as men, and all subjects were non-smokers (cigarettes). Lung volumes and capacities, maximal pressures, and breathing patterns at rest were examined. The following hypotheses were tested: 1) The continual stress of playing a wind instrument may result in certain adaptations of the performer's respiratory and cardiovascular system, 2) at rest, wind players may breathe more slowly and deeply than control subjects (Faulkner, 1967, p. 6), 3) the ratio of oxygen uptake (amount of oxygen absorbed and incorporated by the body) to the amount of air expired may be smaller in wind players than in controls, 4) lung volumes and capacities may be larger in wind players than in control subjects, and 5) when producing a positive airway pressure similar to that of playing an instrument, cardiovascular responses may differ from the controls in that the pulse rate of wind players may not vary as much as the pulse rate of the control subjects before, during, and after holding the pressure for thirty seconds.

NEED FOR THE STUDY

Performance on a wind instrument places many demands on the performer's respiratory and cardiovascular systems.

Some of these physiologic stresses are controlled by the performer. Reflex methods of controlling breathing muscles, lip pressures, air pressures, air flow-rates, and air volumes are developed by the player to produce consistent performance on a wind instrument.

Development of this controlled breathing is crucial for the performer, yet few musicians attempt to understand the physiology involved in developing this control. Explanations of the breathing procedures are often based upon conjectures of the performer or teacher. The teaching of these unsubstantiated ideas of physiologic performance can result in improvement. However, teaching and learning processes may be more reproducible and less frustrating if the factors are clarified in an objective manner. New information can be supplied by continuing formal research in the physiologic aspects of wind instrument performance to alleviate misconceptions and to promote advancement in the understanding and teaching of musical performance.

One basic concern of music educators should be to help students toward more efficient performance with their instruments. However, the literature reveals little experimental activity or interest among musicians concerning the physiology of wind instrument performance.

Edward Rainbow (1973, p. 9) states that the music teacher, "feels a sense of frustration when he tries to find research that is related to problems that are at the core of a substantial portion of his daily chores." He states that he would like to find "objective knowledge of what transpires physically and mentally when a person performs on an instrument." He concludes that "one of the most urgent needs in instrumental music is the development of a theory of instruction based on fact and not speculation."

The fact that musicians have not recognized this deficiency is illustrated by A. Williams (1970), who listed 155 topics for graduate research in Music Education, but only three articles dealt with physiology. All three articles concern health and were listed under "Miscellaneous." The Bulletin of the Council for Research in Music Education (1975), which lists dissertations in progress in United States universities, omits any category that might include physiologic research. Shirmer's Guide to Books on Music and Musicians by R. D. Darrell (1951) lists no heading under "Physiology" and only one listing under "Breathing."

Although the literature available to musicians illustrates little interest in scientific research, some excellent studies have been published. These studies indicate many unsolved problems regarding the physiologic functions of controlled breathing. Relevant studies are discussed in Chapter II, "Related Research."

SIGNIFICANCE

This study should help music teachers and performers in their own understanding of the physiology of breathing and playing wind instruments. Realization of the gross errors and ambiguous statements in the literature may stimulate musicians to examine their own conceptions. Hopefully, they will seek objective methods to understand their own physiologic responses while playing wind instruments.

LIMITATIONS

The Related Research section of this thesis is limited mainly to that research examining respiratory and cardiovascular physiology of wind instrument performance which has been published in the English language. Voice studies are not included. The reader is referred to Heaton and Hargens (1968), who have begun a comprehensive bibliography of physiology and biomechanic studies for the voice.

A second limiting factor in this study is that all subjects were volunteers. Those members of the population who felt they might "measure well" on the tests may have been more anxious to participate, while those who felt they might not "measure well" may have avoided involvement in the study. This may limit the extent to which results can be generalized to a larger population.

PROCEDURES AND DEFINITIONS

Equipment included a six-liter, fast-recording spirometer, a six-liter respirometer, a water manometer, a Wright Peak Flow Meter, a photoelectric finger plethysmograph, and a polygraph. The following parameters of ventilation were measured in each subject.

1. Peak Flow Rate: the maximal velocity of air which can be expired from the end of maximal inspiration.

2. Vital Capacity (VC): the maximal amount of air which can be expired from the end of maximal inspiration.

3. Expiratory Reserve Volume (ERV): the maximal amount of air which can be expired from the end of normal expiration.

4. Forced Expiratory Reserve Volume in One Second (FEV 1 sec): the maximal amount of air which can be expired during the first second of a maximal expiration.

5. Minute Ventilation ($\dot{V}_E$): the amount of air expired during one minute when the subject is resting.

6. Tidal Volume (V_T): the amount of air expired with each breath.

7. Frequency of Breathing (f): the rate at which the subject breathes.

8. Oxygen Uptake ($\dot{V}_{O_2}$): the amount of oxygen absorbed by the body during one minute.

9. Ventilatory Equivalent ($\dot{V}_{E}/\dot{V}_{O_2}$): the ratio of the rate of ventilation to the rate of oxygen consumption at rest.

10. Maximal Expiratory Pressure: the maximal positive airway pressure which can be exerted from the end of maximal inspiration.

11. Maximal Inspiratory Pressure: the maximal negative airway pressure which can be exerted from the end of maximal expiration.

12. Heart Rate Responses to a 30 second breath hold exerting

20 cm H_2O expiratory pressure.

13. Heart Rate Responses to a 30 second breath hold exerting 40 cm H_2O expiratory pressure.

CHAPTER II

RELATED RESEARCH

In an attempt to bring together research efforts of wind instrument performance physiology, Eastman School of Music of the University of Rochester held a seminar on July 11 and 12, 1964. The seminar was entitled "Breathing and Wind Instrument Playing." Coordinators were Wallace O. Fenn, Distringuished Professor of Physiology at the University of Rochester; Arend Bouhuys, Physiologist on leave of absence from the University of Leiden, Holland (now Director of the Lung Research Center at Yale University School of Medicine); and Albert B. Craig, now Professor of Physiology at the University of Rochester. Craig was a supervisor of this thesis.

As a direct result of the Eastman Seminar, the New York Academy of Sciences held a conference on November 7, 8 and 9, 1966 entitled "Sound Production in Man." Bouhuys acted as Conference Chairman and Fenn assumed Honorary Chairmanship of the conference.

This study examines that research involving measurements of lung volumes, breathing patterns, pulmonary gas exchange, mouth pressures while playing wind instruments, and cardiovascular responses to wind instrument performance.

LUNG VOLUMES

Athletes, breath-hold divers, and wind instrumentalists are thought to require larger Vital Capacity (VC) for outstanding performance in their fields. Measurements of Naval Tank Instructors, before and after a year of strenuous breath-hold diving duty, show an actual increase in VC (Schaefer, 1955). Upon comparing lung volumes of the female divers or Ama of South Korea with Korean housewives, the Ama had significantly greater VC and Inspiratory Capacity (IC) than the control subjects (Song, 1963). However, a study of long-distance runners reports no siginificant differences in pulmonary function measurements (Raven, 1977). Investigations involving wind instrumentalists present conflicting results.

Borgia (1975) and Naurátil (1968) found no significant lung volume differences when comparing instrumentalists to standard tables of normal values. Studies by Stauffer (1968), Tucker (1971), and Bouhuys (1964) indicate that wind instrumentalists may indeed have larger VC than control subjects. Stauffer (1968) measured VC of 63 male wind instrumentalists in the U.S. Navy Band and found VC 8.7% greater in the wind instrumentalists than in predicted normal values according to height and age. Since the Navy is a selected population and the control study involved some hospital patients as subjects, results are open to question.

Tucker (1971) compared measurements of 45 male brass players to results of two tables of standard normal values and found that the wind players measured significantly greater VCs, Total Lung Capacities (TLCs), Expiratory Reserve Volumes (ERVs), and Residual Volumes (RVs) than the control values. The RV/TLC ratio and maximum mid-expiratory flow rate (MMF) were also greater in brass players than control values.

Bouhuys measured lung function of 40 professional wind instrumentalists and compared the results with those of healthy male subjects. VC was significantly greater in wind players than expected according to age and height.

Äkgün and Özgönül (1967) compared breathing patterns and lung volumes of 17 male zurna (a Turkish double-reeded instrument) players with those of 17 male control subjects of similar characteristics. VC and maximal expiratory and inspiratory flow rates were significantly smaller in zurna players than in the controls. RV and RV/TLC were greater in players than in controls. These results indicate that the wind players did not compare favorably with the control subjects. The smaller VCs of the wind players may be due to the fact that more wind players than controls had histories of heavy smoking.

MEASUREMENTS OF PULMONARY VENTILATION

Breathing patterns during performance on wind instruments consist of deep, rapid inspirations followed by prolonged expirations (Bouhuys, 1964). Muhar has recorded slow, deep breathing habits of wind instrumentalists and singers at rest (Faulkner, 1967, p. 6). There is a need for more detailed studies of the breathing habits of wind instrumentalists at rest as compared with those of normal, healthy subjects.

WIND INSTRUMENT PRESSURES

In order to produce tones on a wind instrument, specific airway pressures and flow rates are required. These pressures have been measured by several methods (Bouhuys, 1964, 1968; Vivona, 1968; Navrátil, 1968; Tucker, 1968; Frucht, 1937; Roos, 1936; Stone, 1874; Barton and Laws, 1902).

With a balloon-catheter, Bouhuys (1968) measured mouth pressures during performances on wind instruments. In order to measure lung volume changes simultaneously with the mouth pressures exerted, the subject was seated in a volume-displacement body plethysmograph. Bouhuys concluded that in order to maintain a constant pitch and dynamic level on a wind instrument, one must maintain a constant mouth pressure and airflow rate. He observed that with increasing dynamic levels, both mouth pressures and flow-rates increase. Oboe requires moderate airway pressures but very small flow rates. Trumpet and horn require very high pressures and small flow rates. Flute and tuba require low pressures and high flow rates. Although most instruments require greater pressures for production of the highest pitches, the clarinet requires higher pressures for production of the lowest note on the instrument than for higher pitches (Bouhuys, 1968, p. 266).

Vivona (1968) recorded mouth pressures during performance on trombone by placing a small tube in the corner of the trombonist's mouth. Measurements determined that mean pressures in the oral cavity differ among subjects, and those pressures differ with each individual from one performance to the next of the same pitch at the same dynamic level. Consistancy of oral pressure within different days and trials did not affect the quality of performance on the trombone.

Berger (1964) measured intraoral air pressure with a small tube placed in the corner of the trumpet player's mouth while tones were being produced at different pitches and dynamic levels. Flow rate was also measured. Loud tones were found to require a greater quantity of air flow for all pitches than did soft tones. However, for soft tones, the middle pitches required less air than did each extreme pitch level (Berger, 1964, p. 1217).

Pressures required to play wind instruments range from about 0.75 centimeters (cm) of water (H_2O) pressure in tuba (Roos, 1936, p. 3) to about 200 cm H_2O pressure in trumpet (Bouhuys, 1964, p. 973). Although the pressures required to produce tones on brass instruments include a wider range of pressures than those required to play wood-winds, most wind instruments can produce tones at pressures between 20 cm H_2O and 60 cm H_2O (Bouhuys, 1964, p. 973; Navrátil, 1968, p. 278).

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MAXIMAL PRESSURES

Although there are no standard tables of normal values for maximal pressures, Craig (1960, p. 1099) has graphed average maximal pressures at different lung volumes for ten normal male subjects. Maximal expiratory pressure averages +180 cm H_2O pressure and maximal inspiratory pressure is -130 cm H_2O pressure. Data by Rahn (1946, p. 163) average +146 cm H_2O ± 7 maximal expiratory pressure, and -117 cm H_2O ± 8 maximal inspiratory pressure.

CARDIOVASCULAR RESPONSES

A breath hold, accompanied by a rise in airway pressure, is known as a Valsalva maneuver. The Valsalva maneuver results in specific cardiovascular responses:

> At the very onset of the increased intrathoracic pressure there is a transient slowing of the heart rate. The increased pressure is transmitted directly to the peripheral arteries including the carotid sinus which is thought to be the site of the afferent signal.
>
> Increased intrathoracic pressure also hinders venous return from the extremities, and as the thoracoabdominal venous supply returning to the heart is depleted, cardiac output and arterial pressure fall, and the heart rate increases. However, the decrease in arterial pressure and the tachycardia are usually limited by an increase in peripheral venous pressure, the re-establishment of venous return from the extremities, and the maintenance of the cardiac output. During this phase of the Valsalva maneuver stroke volume is below normal, but cardiac output is adequate to maintain the arterial pressure if the rate is increased. (Craig, 1963, p. 859.)

Similar physiologic responses occur during performance on a wind instrument (Faulkner and Sharpey-Schafer, 1959; Tucker, 1968; Borgia, 1975). Upon production of a tone, there is a resultant bradycardia (slowing of the pulse rate). The pulse rate then begins a tacycardia (increasing pulse rate) which increases until the release of the pressure. At the release of the pressure, there is a dramatic bradycardia. From this point, pulse rate gradually increases speed until normal rate is attained. (Tucker, 1968, p. 329.) Pulse rate changes vary proportionately to the degree of pressure produced (Craig, 1963, p. 859).

Of the wind instruments, trumpet requires the greatest pressures. Syncope[1] often occurs with players who are producing unusually high or loud pitches because of the unusually great pressures required.

[1]Dizziness or "blacking out" due to lack of oxygen to the brain.

CHAPTER III

METHODS

SUBJECTS

All subjects were students or faculty at the Eastman School of Music of the University of Rochester. Nine subjects were also members of the Rochester Philharmonic Orchestra. Twenty-one male wind players and twelve female wind players comprised the experimental group. The control group consisted of ten male and six female Eastman musicians who play non-wind instruments (keyboard, strings and percussion). Informed consent forms (see Appendix I) were signed by each subject. Participation was voluntary.

Instruments: Nineteen woodwind instrumentalists participated in the study (seven male clarinetists, two male and two female oboists, and four female flutists). Fourteen brass instrumentalists were studied (four male trumpet players, five male and one female trombonists, and one male and three female French horn players).

PULMONARY FUNCTION

Peak Flow: The Wright Peak Flow Meter is a cylindrical instrument about 13 cm in diameter and 4 cm deep (Wright and McKerrow, 1959, p. 1043). A movable mouthpiece is attached. The Peak Flow Meter is "a simple and reliable device for measuring the maximum expiratory flow rate during a forced expiration, which in turn is put forward as a stable and useful measure of ventilatory capacity." (Wright and McKerrow, 1959, p. 1046). Some attempts have been made to predict normal values for Peak Flow Rate (Tinker, 1961). Studies to this purpose are few and serve mainly to predict the feasibility of the Peak Flow Rate measurements from this study.

The subject was instructed to apply the noseclip, inhale a deep breath through the mouth, place the mouthpiece in the mouth, and to blow into the mouthpiece as hard as possible. After a trial, which was allowed in order for the subject to become acquainted with the lack of resistance in the apparatus, the procedure was conducted three times. The maximal reading of the three attempts was used as the Peak Flow Rate.

Spirometer: Most pulmonary volumes and capacities can be measured with a spirometer. Guyton (1966, pp. 550-551) defines the spirometer:

> This consists of a drum inverted over a chamber of water, the drum counterbalanced by a weight. In the drum is a breathing mixture of gases, usually air or oxygen, and a tube connects the mouth with this gas chamber. On breathing in and out of the chamber the drum rises and falls, and an appropriate recording is made on another drum. When using this spirometer only a few breaths can be recorded because of the buildup of carbon dioxide and loss of oxygen from the gas chamber.

Clinically, the spirometer determines change in VC due to the development of or recovery from some lung or heart diseases. VC is determined by the physical characteristics of an individual, strength of respiratory muscles, and the ability of the lungs and chest cage to stretch, or pulmonary compliance (Guyton, 1966, p. 552).

For this experiment, a Collins six-liter, fast-recording spirometer was used to measure VC and FEV1sec (the percentage of VC that can be exhaled within the first second of maximal forced expiration). The drum was pushed down into the chamber of water so that no air remained in the drum. The subject was seated and instructed to keep posture erect. S/he was then instructed to apply the noseclip and inhale deeply while holding away from the mouth, the tube attached to the spirometer.

After full inspiration, the subject exhaled as hard, fast and completely as possible into the tube. In order to ensure that the subject exhaled the greatest amount of air possible at the greatest possible rate, the researcher watched the recording needle on the drum and verbally encouraged the subject to "push" until the recording registered no more air entering the drum. At that time, the subject was instructed to stop blowing and to relax. After a brief rest, the subject was asked to repeat the procedure two more times. The greatest VC of the three attempts and the average FEV1sec were obtained. The average FEV1sec was also calculated as a percentage of the maximal VC. All volumes were corrected to Body Temperature Pressure Standard (BTPS).

The Respirometer differs from a fast recording spirometer in that the recording drum rotates slowly intead of rapidly. A container of soda lime is placed inside the respirometer to absorb carbon dioxide and the drum is filled with oxygen in order for the subject to breathe in and out through the attached tube for several minutes.

In this study, a Collins six-liter recording respiro meter was utilized to measure Tidal Volume (TV), breathing frequency (f), Minute Ventilation (V_E), Expiratory Reserve Volume (ERV), Vital Capacity (VC), Oxygen Uptake ($\dot{O}_2$) and Oxygen Equivalent of breathing ($\dot{V}_{E/\dot{O}_2}$).

The subject was seated facing away from the respirometer so that the drum could not be seen by the subject. Erect posture was emphasized. The subject applied the nose-clip and placed the respirometer mouthpiece in the mouth. S/he was then instructed to breathe quietly, in and out of the mouthpiece, for two or three minutes. After several minutes of relaxed breathing, the subject was instructed to inhale deeply through the mouthpiece; then to exhale all of the air into the mouthpiece. As the subject exhaled, the researcher verbally encouraged the subject to "push" out all of the air. This procedure was repeated two more times during the five to six minute period during which the subject breathed in and out through the respirometer mouthpiece.

TV, f, and $\dot{V}_E$ were averaged for one minute. ERV was averaged for the three attempts. Average ERV was calculated as a percentage of maximal VC. Oxygen uptake ($\dot{O}_2$) was averaged over five minutes using the CO_2 reading on the respirometer tracing as an equivalent index to oxygen uptake. All volumes were corrected to BTPS except for the oxygen uptake, which was corrected to Standard Temperature Pressure Dry (STPD). The oxygen equivalent of breathing was determined by the ratio of $\dot{V}_{E/\dot{O}_2}$.

HEART RATE RESPONSE

Cardiovascular responses to playing wind instruments have been studied (see "Related Research"). Since only wind instrumentalists can be studied during wind instrument performance, no studies have included control subjects. A method was devised to examine both wind instrumentalists and control subjects (other musicians who play non-wind instruments). Pulse rate was obtained with a photo-electric finger plethysmograph. Pressure was recorded by attaching a water manometer to a pressure transducer, which was attached to a polygraph. Pulse rate was obtained before, during and after a 30 second breath hold during which the subject produced a positive airway pressure similar to those required to play wind instruments.

A finger plethysmograph reflected pulsatile flow in the finger. Pulse recordings were obtained by attaching the plethysmograph to a polygraph.

A water manometer consists of a tall, U-shaped glass tubing which is filled with water, to the center of the tubing so that each side of the U-shape contains half of the water. Positive and negative air pressures can be measured by balancing against the column of water in the tube. The manometer was attached to the polygraph by means of a pressure transducer. This enabled a recording to be made.

Heart rate responses to two separate pressures were measured for each subject. The pressures measured were 20 cmH_2O and 40 cmH_2O. Those pressures were chosen because they have been previously studied (Craig, 1966), are easily maintained for 30 seconds, and are within the pressure range required on most wind instruments to produce tones (Bouhuys, 1964, p. 972; Roos, 1936, p. 3).

To record heart rate response to a 30 second breath hold, the subject, while seated, was asked to rest the right arm on a slightly inclined surface. The photo-electric finger plethysmograph was placed on the middle finger of the right hand. The subject was instructed to keep that hand relaxed and not to move the middle finger. The tube attached to the manometer was held by the left hand. Polygraph recording paper was set at 10 /second. In order to obtain a control pulse for each breath hold, the researcher counted 25 pulses after an initial settling of the pulse rate, then instructed the subject to inhale deeply and blow into the tube. Upon blowing into the tube, the water level in the tube would move. The subject was instructed to attempt to hold the water pressure at the first red line, which marked 20 cmH_2O pressure. When the water level began to move, the researcher started the timer. After 30 seconds the subject was instructed to stop holding the pressure, to relax, and breathe normally while the recorder continued measuring pulse for a 60 second recovery period. After normal pulse rate returned, the same procedure was repeated two more times. The subject was then instructed to repeat the procedure while holding the water level on the second red line, which measured 40 cmH_2O pressure. This procedure was measured three times.

The experiment was conducted three times at each pressure. The average heart rate for each experiment was determined by averaging 20 pulses (20 x 60 ÷ cm of paper in 20 pulses). Pulse rate for the 30 second breath hold and 60 second recovery period was determined by averaging the pulse rate over five second intervals throughout the 90 second period (# of pulses in 5 seconds x 60 ÷ cm of paper in 5 seconds). The average control pulse for the three trials at each pressure was counted as the average control pulse for that pressure. For the three trials at each pressure, the average pulse rate was calculated for each five second interval, throughout the 90 second period.

MAXIMAL PRESSURES

The pressure transducer was calibrated with the water manometer. The tube attaching the water manometer to the tube held by the subject was then clamped off so that the production of high pressures would not exceed the capacity of the water manometer. Instead, the pressures were recorded directly onto the polygraph.

After maximal inspiration, the subject was asked to blow as hard as possible into the tubing, which was attached to the pressure transducer. This procedure was repeated two more times.

Secondly, the subject expired maximally and attempted to establish a maximal inspiratory pressure through the tubing. Three attempts to measure maximal inspiratory pressures were obtained in this manner. The subject was warned not to "suck in" with cheek muscles. The greatest of the three expiratory pressure measurements and the greatest of the three inspiratory pressure measurements were used as the maximal pressure measurements.

CHAPTER IV

RESULTS

The results of the different tests were averaged for control and wind-player groups according to sex. The wind-player groups were also averaged for each instrument. Standard errors of the mean for each of the groups were calculated. Using Student's t test, differences were considered significant at $p \leq .05$ or at $p \leq .01$. Most testing for significance was conducted between wind-player groups of each sex and their respective controls.

LUNG VOLUMES

There were no significant lung volume differences between wind players and controls (Table 1, p. 23). Both male and female wind instrumentalists had significantly greater VC than their respective control groups. However, when measurements were compared with standard values (Morris, 1971),[1] which correct for sex, age, and height, there was no significant difference. Male wind players were taller and heavier than male controls, and female wind players were heavier than female controls. Therefore, predicted VC was greater for wind-player groups.

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[1]Morris (1971) was chosen as a comparison study because:
1) This study represented a non-smoking population.
2) It was a large sampling (471 women, 517 men).
3) No subjects were hospital patients.

Table 1: Age, Physical Characteristics, forced vital capacity (FVC) and expiratory reserve volumes (ERV) of subjects.

Subjects	N	Age yr.	Height cm	Weight Kg	FVC ℓ	FVC % Pred.	E.R.V. ℓ	E.R.V. % V.C.
Control, Male	10	26.5 1.0*	176.6 5.5	68.0 1.3	5.0 .06	93% .8	1.6 .06	32% 1.0
Wind, Male	21	28.5 .6	181.1 .8	79.0 .8	5.3 .03	95% .4	1.6 .02	31% .4
Control, Female	6	25.2 1.0	161.6 .7	52.1 .7	3.6 .06	94% 2.0	1.3 .03	39% .6
Wind, Female	12	22.2 .3	163.5 1.5	60.6 1.0	4.0 .05	96% .8	1.6 .04	40% .8
Trumpet, Male	4	23.0 1.5	182.1 1.4	80.2 2.3	5.7 .1	99% 2.1	1.4 .13	26% 1.9
Trumpet Female	0							
Trombone, Male	5	29.0 2.8	181.0 1.1	78.5 3.8	5.5 .06	100% 1.5	1.8 .05	35% 1.3
Trombone, Female	1	20	166.0	49.	3.5	84%	1.3	40%
French Horn, Male	1	19	180.3	68.0	5.3	91%	1.5	29%
" " Female	3	20.7 1.5	165.0 3.3	60.5 2.4	4.0 .4	95% 6.6	1.5 .15	39% 2.3
Oboe, Male	2	49.0 17.0	179.6 6.2	77.1 12.8	4.7 .2	95% 3.5	2.1 .7	41% 12.7
Oboe, Female	2	21.5 .7	156.1 1.8	51.0 1.6	3.8 .2	101% 7.1	1.4 .2	38% 4.2
Bassoon, Male	2	27.0 8.5	182.3 17.1	73.5 18.6	5.6 .3	98% 7.8	1.8 .05	34% 1.4
Bassoon, Female	2	21.0 1.4	172.1 2.7	70.3 16.0	4.5 .03	101 2.0	1.4 .56	33% 9.0
Flute, Male	0							
Flute, Female	4	24.8 1.5	170.4 2.3	63.5 3.8	4.1 .2	96% 2.8	1.9 .2	46% 3.8
Clarinet, Male	7	27.1 2.4	180.7 1.5	71.9 1.8	4.9 .13	90% 1.5	1.4 .08	28% 1.4
Clarinet, Female	0							

*S.E.

Table 2: Functional characteristics of subjects: forced expiratory volume in 1 second (FEV_1), maximal peak expiratory flow rate (Peak Flow) and maximal expiratory pressure and maximal inspiratory pressures (max. pres., exp. and insp.) after maximal inspiration and expiration, respectively.

		FEV_1			Peak Flow	Max. Pressures	
	N	ℓ	% V.C.	% Pred.	ℓ/min.	exp. torr	Insp. torr
Control, Male	10	4.1	82	95%	567	132	104
		.05*	.6	1.2	10	4	5
Wind, Male	21	4.3	80	96%	573	155	116
		.04	.5	.7	5	2	3
Control, Female	6	2.8	78	92%	368	80	48
		.08	1.7	2.9	15	2	2
Wind, Female	12	3.3	82	96%	414	110	68
		.04	.6	1.0	6	1	2
Trumpet, Male	4	4.7	82%	102%	623	208	131
		.2	2.0	3.9	27	19	28
Trumpet, Female	0						
Trombone, Male	5	4.6	83%	105%	628	130	88
		.1	1.6	1.7	16	5	10
Trombone, Female	1	2.6	75%	78%	355	130	107
French Horn, Male	1	3.5	66%	75%	440	108	98
" " female	3	3.5	88%	104%	435	104	59
		.4	.9	8.2	54	11	8
Oboe, Male	2	3.8	80%	104%	548	180	100
		.2	0	3.5	32	21	28
Oboe, Female	2	3.2	85%	105%	380	110	84
		.1	7.1	.7	28	7	5
Bassoon, Male	2	4.6	83%	104%	550	133	90
		.3	0	2.1	85	4	18
Bassoon, Female	2	3.4	77%	97%	428	114	60
		.2	3.5	7.8	53	3	32
Flute, Male	0						
Flute, Female	4	3.3	79.5	96%	425	107	59
		.2	2.4	4.4	15	4	15
Clarinet, Male	7	3.9	79%	86%	540	150	143
		.2	2.4	2.3	22	4	8
Clarinet, Female	0						

* = S.E.

Table 3: Pulmonary ventilation and gas exchanges of subjects: Tidal volume (V_T), frequency of ventilation (f), rates of ventilation ($\dot{V}_E$), rates of oxygen consumption ($\dot{V}_{O_2}$), and ventilatory equivalent ($\dot{V}_E/\dot{V}_{O_2}$)

	V_T ℓ	f breath/min	$\dot{V}_E$ ℓ/min	$\dot{V}_{O_2}$ ℓ/min	$\dot{V}_E/\dot{V}_{O_2}$
Control, Male	1.3 .10*	8.7 .4	10.7 .7	.36 .01	29.0 1.5
Wind, Male	1.2 .03	7.5 .1	8.6 .2	.38 .01	24.8 .6
Control, Female	.7 .04	10.2 .6	7.1 .4	.31 .02	23.2 1.3
Wind, Female	.8 .03	10.6 .2	8.1 .3	.32 .01	26.5 .8
Trumpet, Male	1.0 .1	7.0 .8	6.9 .8	.30 .1	22.1 4.7
Trumpet, Female	0				
Trombone, Male	1.5 .2	5.7 .4	8.1 .6	.30 .01	23.5 .9
Trombone, Female	.6	11.	6.2	.24	37.8
French Horn, Male	1.4	4.	5.5		
French " Female	.8 .1	13.3 1.4	10.0 2.3	.3 .04	28.3 4.6
Oboe, Male	.9 .1	11.5 3.5	9.6 2.1	.3 .05	29.6 10.4
Oboe, Female	.5 .1	10.5 3.5	5.9 3.2	.3 .1	22.1 17.1
Basson, Male	1.0 .1	9.2 1.8	9.1 2.5	.4 .1	23.9 11.4
Bassoon, Female	.6 .1	10.5 .7	6.3 .8	.4 .06	18.0 5.0
Flute, Male	0				
Flute, Female	1.1 .1	8.5 .2	9.0 .9	.3 .03	28.9 1.2
Clàrinet, Male	1.4 .1	7.9 .4	10.1 .6	.4 .01	28.4 2.3
Clarinet, Female	0				

For both males and females, ERV and ERV as a percentage of VC were not significantly different for wind players than for controls.

FEV 1 sec, for both male and female wind players, was significantly greater than for respective control groups (Table 2, p. 24). When FEV 1 sec was corrected to standard tables (Morris, 1971), there was no longer a significant difference between wind players and controls. Since VC was greater in wind players, FEV 1 sec was expected to be greater as well. FEV 1 sec was greater, but FEV 1 sec, expressed as a percentage of VC, was not.

Female wind players had significantly greater Peak Flow Rates ($p \leq .05$) than female controls. There was no significant difference in Peak Flow Rate between male wind players and male controls (Table 2, p. 24).

MAXIMAL PRESSURES

Both maximal expiratory and inspiratory pressures were significantly greater in wind players than in controls (Table 2, p. 24). Maximal expiratory pressure of male winds was significantly greater than controls at $p \leq .01$, and maximal inspiratory pressure was also greater at $p \leq .05$. Both maximal expiratory and inspiratory pressures of female wind players were significantly greater than female controls at $p \leq .01$.

PULMONARY VENTILATION

Table 3, p. 25 , illustrates that breathing frequency,

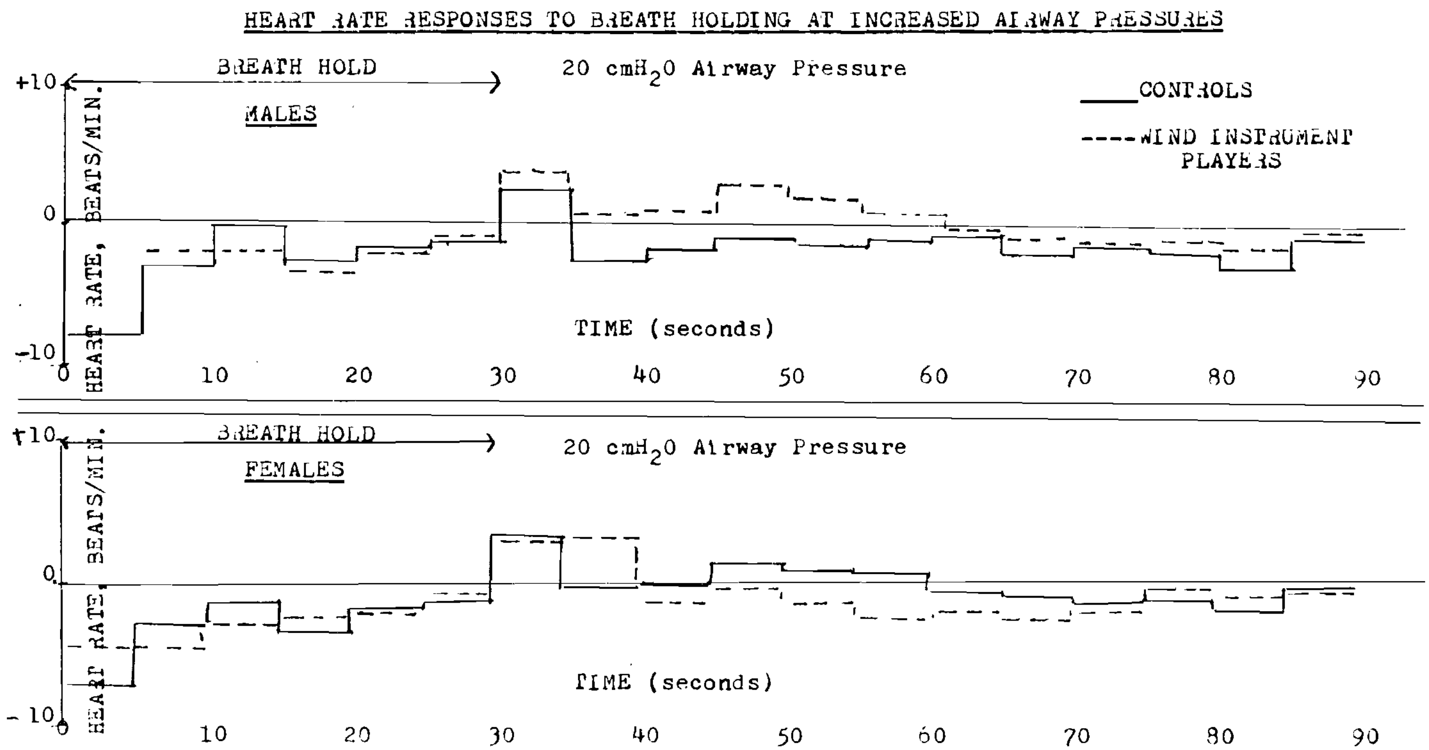

Figure 1. Average Heart Rate Responses to Breath Holds (30 seconds) for Wind Players and Controls. Zero on the X axis represents control Heart Rate. The top graph represents 21 male wind players and 10 male controls. Average heart rate for male control subjects was 72 beats/min. and for male wind players, 74 beats/min. The lower graph represents 12 female wind players and 6 female control subjects. Average pulse rate for the female controls was 75, and for the female wind players, 63. All lung volumes were 80% VC.

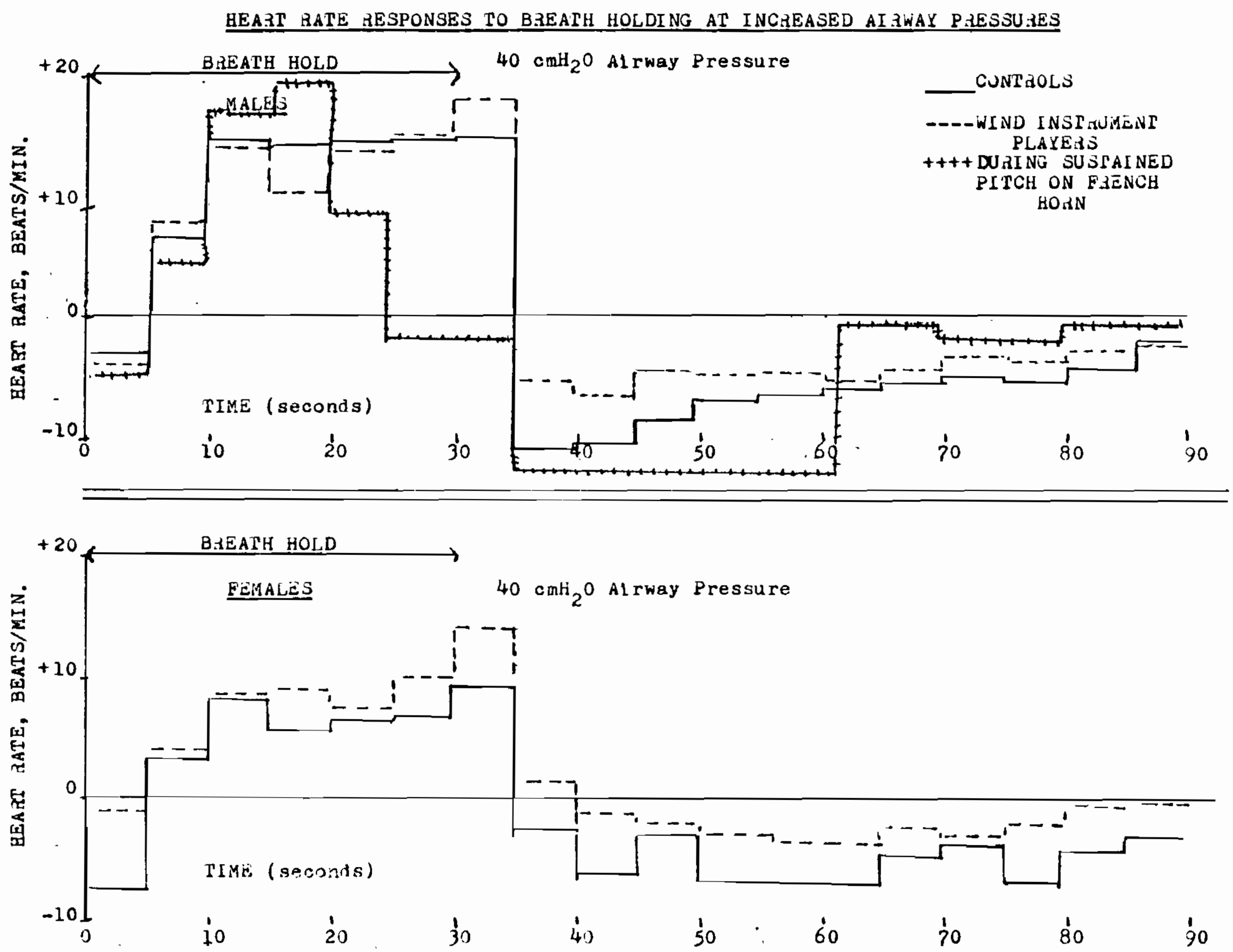

Figure 2. Average Heart Rate Responses to Breath Holds (30 seconds) for Wind Players and Controls. All lung volumes were 80% VC. Zero on the X axis represents Control Heart Rate. The top graph shows responses of 21 male wind players and 10 male control subjects. Average heart rates for these two groups were: male wind players, 73, and male controls, 70. The ++++ line is the heart rate during a sustained pitch (30 seconds) on the French Horn.

PREVIOUS STUDY (CRAIG)

HEART RATE RESPONSES TO BREATH HOLDING AT INCREASED AIRWAY PRESSURES

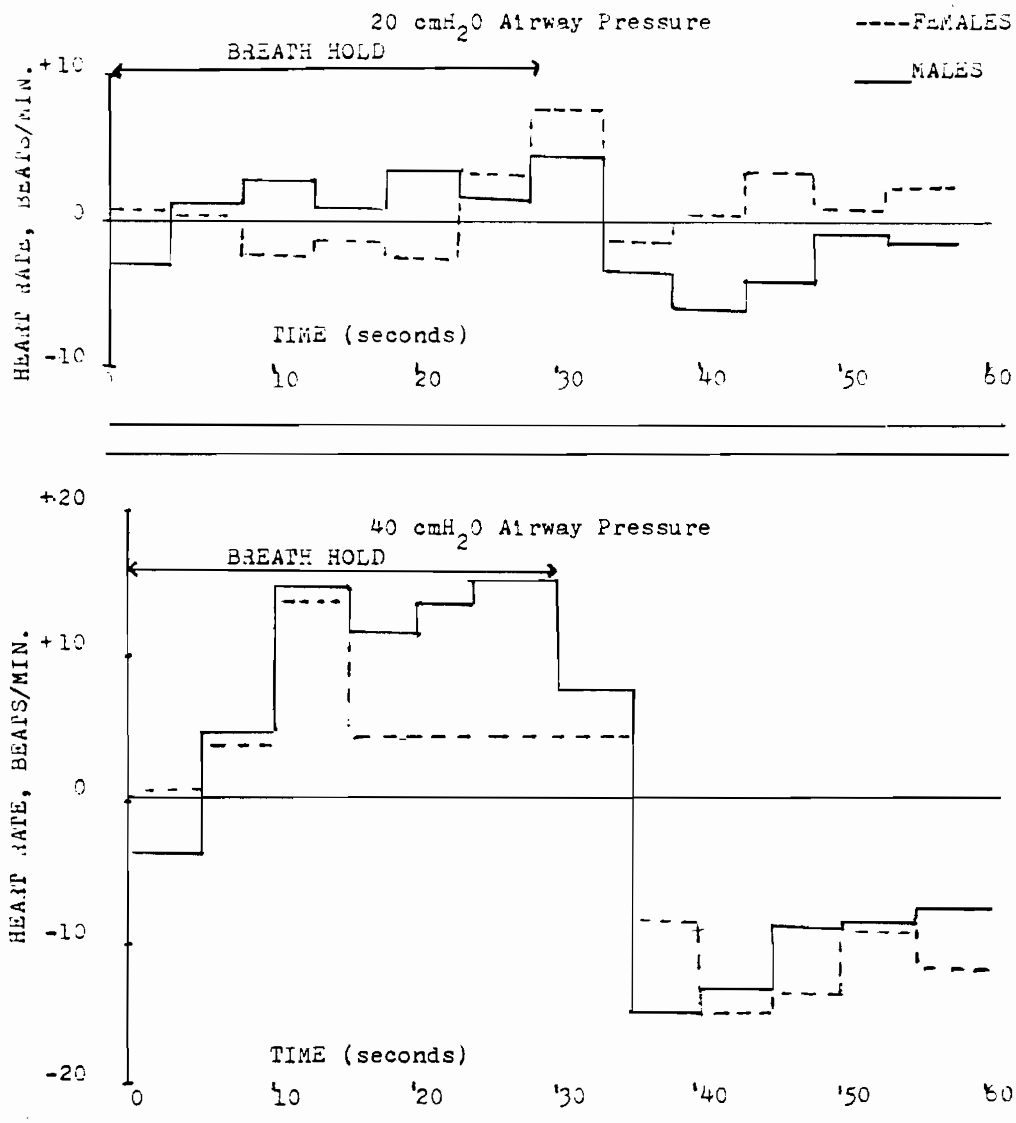

Figure 3. Average Heart Rate Responses to Breath Holds (30 seconds) for 15 males and 9 females at lung volumes of 80% VC. Average control heart rate for males was 80 beats/min. Average control heart rate for females was 87 beats/min. Zero on the X axis represents Control Heart Rate. Data from an unpublished study by Craig, 1966.

HEART RATE RESPONSES TO BREATH HOLDING AT INCREASED AIRWAY PRESSURES

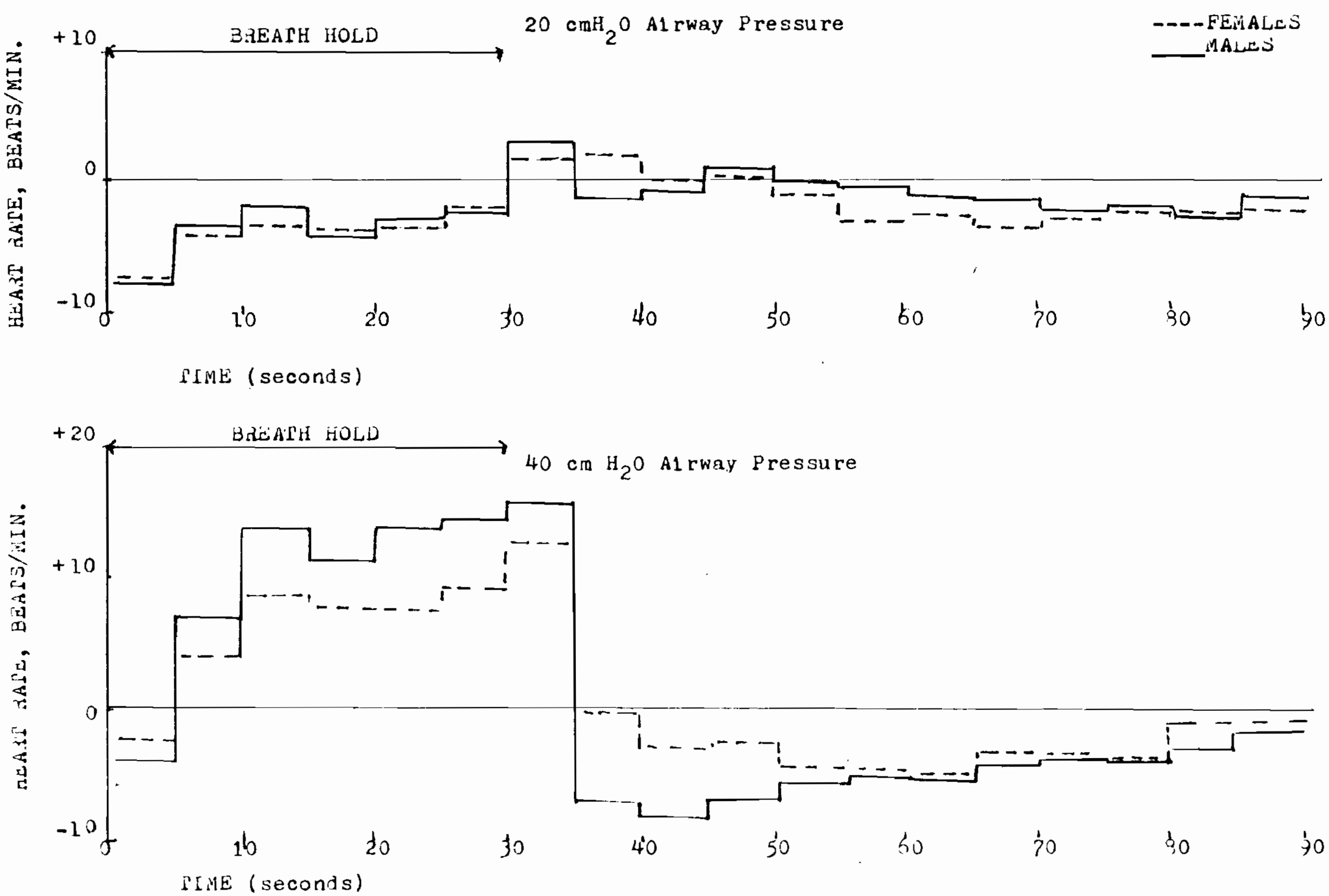

Figure 4. Heart Rate Responses to Breath Holds (30 seconds) for Males and Females at Increased Airway Pressures of 20 cm H_2O and 40 cm H_2O. Zero on the X axis is control heart rate. This graph represents the combined averages of Figures 1. and 2.

Minute Ventilation ($\dot{V}_E$), and $\dot{V}_E/\dot{V}_{O_2}$ were slightly but significantly less ($p \leq .05$) in male wind players than in male controls. There were no significant differences between female wind players and female controls.

HEART RATE RESPONSE

Heart rate responses to breath holding at increased airway pressure did not differ between wind players and controls (Figures 1 and 2, p. 27). There was, however, a significant difference between male and female responses (Figure 4, p. 30). The heart rate responses of the female changed less during and after a 30-second breath hold with increased pressure of 40 cm H_2O than those of the males. These results agree with unpublished data by Craig (Figure 3, p. 29).

CHAPTER V

DISCUSSION

LUNG FUNCTION

Peak Flow Rates were compared with those reported by Tinker (1961) in order to determine reliability of the measurements for males from this study. The youngest age group measured by Tinker was males 30-34 years of age. In this study, control males averaged 26.5 years of age, and male wind players averaged 28.5 years of age. Average Peak Flow Rate for the youngest age group in Tinker's study was 622 liters/minute. As seen in Table 1, p. 23, all male averages for this study fall within this range.

Since Peak Flow Rate has not previously been studied in wind instrument players, results of wind instrumentalists from this study were compared with controls from this study.

Male Peak Flow Rates did not differ between controls and wind players, but Peak Flows for female winds were significantly greater ($p \leq .05$) than for female controls.

Peak Flow Rate may be related to the strength of expiratory muscles. One would expect a positive correlation of Peak Flow Rate and maximal expiratory pressure. However, the correlation coefficient of Peak Flow and maximal expiration pressure for females was $r = .07$ and for males was $r = .32$. Therefore, there was no direct correlation to substantiate the assumption.

LUNG VOLUMES

Lung volume measurements agreed with studies by Naurátil (1968) and Borgia (1975), who found no significant differences between wind players and controls. Results indicated that playing wind instruments does not change VC. Since wind instrument players did not have larger VC than predicted for age and height, assumptions are unfounded which indicate that large VC is necessary for successful wind instrument performance.

Lung volume measurements differed from those of Akgün and Özgönül (1967) and from those of Bouhuys (1964) and Tucker (1971). Akgün and Özgönül (1967) reported lesser VC in wind players than in controls. A large percentage of cigarette smokers in the wind player group studied by Akgün and Özgönül may account for these results. The current study included no cigarette smokers and only one pipe smoker.

Bouhuys (1964) and Tucker (1971) found significantly greater VC in male brass players than in controls. Controls for Bouhuys' study were results from two previous experiments using prison guards and inmates, and textile workers as subjects. Out of 108 subjects, 74 were considered healthy. Control subjects for Tucker's study included some hospital patients. Perhaps differences would not be significant when compared with a control group consisting of only healthy individuals.

Although VC of wind players in the current study was not greater than predicted, the average VC of wind players was greater than that of controls because wind players were taller than controls. In order to determine whether the average height and weight of wind players is greater than those of controls due to selection, a study should be conducted which compares heights and weights of the personnel of an entire orchestra or music school. The wind musician should be compared with the non-wind musicians of that population. If wind players do have greater VC than normal, healthy individuals, it may be because those people with small VC may find it difficult to achieve professional levels of performance on wind instruments, and are therefore less likely to pursue wind instrument performance as a career (Bouhuys, 1964, p. 972).

PULMONARY VENTILATION

Breathing frequency may be slightly slower in male wind players with slightly less Minute Ventilation ($\dot{V}_E$). $\dot{V}_E/\dot{V}_{O_2}$ may also be slightly less in wind players. These results agree with the impressions of Muhar (Faulkner, 1967, p. 6). It is possible that wind instrumentalists have slightly different breathing habits at rest related to the breathing processes required during wind instrument performance.

Frequency of respiration increases with increase in percentage of CO_2 in the air.

Wind players may be less sensitive to CO_2, and may therefore breathe slightly slower than other people. The sensitivity to CO_2 of wind instrumentalists as compared to a group of controls should be measured.

MAXIMAL PRESSURES

Both male and female wind players were able to produce greater expiratory and inspiratory pressures than their respective control groups. Trumpet requires the greatest pressures and trumpet players had the greatest expiratory and inspiratory pressures. Trumpet players, followed by oboists and clarinetists, accounted for the greatest pressures in males. All female wind player groups had greater pressure values than female controls.

Maximal male pressures were compared with two studies of average maximal pressures at different lung volumes (Rahn, 1946; and Craig, 1960). Control male averages for maximal pressures in the current study were +132 cm H_2O pressure $\pm$ 4 and -104 cm H_2O pressure $\pm$5, and for male wind players, +155 cm H_2O pressure $\pm$2 and -116 cm H_2O pressure $\pm$3. Average maximal pressures for Rahn (1946) were $\pm$146 cm H_2O pressure $\pm$7 and -117 cm H_2O pressure $\pm$8. Rahn's averages are similar to averages for the current study. Craig's (1960) averages were +80 cm H_2O pressure and -130 cm H_2O pressure, which are greater than those of the current study. However, subjects for Craig's study were not considered within the normal population in that they were all very healthy medical and graduate students who were exhorted to obtain maximal pressures.

Both male and female wind players in this study had significantly greater expiratory and inspiratory pressures. This difference may be attributed to an adaptation of the respiratory system due to the strain created by the muscular stresses of wind instrument performance.

Exercise increases muscular strength because muscles adapt to the strain which is placed on them by the stress of exercise. If wind instrument performance demands do stress the respiratory system, one might expect resultant adaptations.

Wind instrument performance demands include the production of positive airway pressures and airflow rates, and control of respiratory muscles. Some of these demands are described by Bouhuys:

> In all instruments except the clarinet mouth pressure rises with frequency and with sound level. The clarinet is exceptional in that mouth pressure decreases at high notes. . . The pressure rise with frequency is much more pronounced in brass than in woodwinds. Thus, precise control of mouth pressure is of greater importance for the brass player than for most woodwind players. The variability of mouth pressure with both frequency and sound level means that the same mouth pressure level may be used to blow different notes at different sound levels, e.g., a low note ff or a higher note pp. Which note will result at any given pressure is determined by the effective length of the instrument, which can be changed by opening or closing the side holes in woodwinds or the pistons in brass, and by the position of the lips of the player. (Bouhuys, 1964, p. 973).

Maximal VC is a function of lung volume. Maximal pressures are different at different lung volumes. High brass pressures can only be maintained from 80% VC to between 30% and 50% VC (Bouhuys, 1964, p. 973).

> With instruments and notes requiring a high pressure, the duration during which a note can be sustained decreases when the required pressure is near the maximum expiratory pressure (French horn, trumpet). On instruments and notes requiring high flow rates but only moderately high pressures, nearly the full VC can be utilized (piccolo, bass tuba). On the other hand, the time during which an oboe player can sustain a note is apparently not limited by the pressure and air flow requirements of his instrument, but by his breath-holding time. (Bouhuys, 1964, p. 974).

Playing a wind instrument requires voluntary control of a constant pressure. Bouhuys has examined the muscular actions which occur during production of a constant pressure.

> To accomplish a simple action like breathing out against a constant pressure requires a complex motor act which involves precise regulation of the state of contraction of both inspiratory and expiratory muscles. . . Chest volume decreases at an even rate, pressure in the airways is constant, and the contraction state of the muscles, on the other hand, changes continuously throughout this act (Bouhuys, 1969, p. 1).

CARDIOVASCULAR RESPONSES

Wind instrument performance also places demands, or stress, on the cardiovascular system. Cardiac arrhythmias have been reported in French horn players and trumpet players during performance (Tucker, 1971; and Borgia, 1975). Out of 75 French horn players, Borgia reported that 28% demonstrated premature contractions during electrocardiogram testing. Tucker reported arrhythmias in trumpet and French horn players. He also reported more cardiac arrhythmias during periods of heavy trumpet practice than during periods of little practice. However, many types of irregularities in electrocardiograms are not considered abnormal.

A study of the causes of death in union musicians (Tucker, 1971, pp. 331-332) reported that although the average age of death in musicians was 54 as compared to normal life expectancy of 69 years, the incidence of death caused by coronary heart disease was only 56.1% in musicians as compared to 53.5% in the normal population. This indicates that wind instrument performance does not create severe stress on the cardiovascular system.

PULSE RATE RESPONSES

Pulse rate responses during wind instrument performance are an indication of respiratory as well as cardiovascular responses (Craig, 1965). The heart is located in the intrapleural space and responds to intrapleural pressure changes by changes in heart rate.

Airway pressures are created by a combination of the elastic rebound of the lung and by intrapleural pressures. When there is equal pressure on the lung to expand and to contract, the intrapleural pressure is about -5 cm H_2O. If a subject inspires 80% VC, then relaxes, the elasticity of the lungs produces 20 cm H_2O pressure and the intrapleural pressure is zero (Rahn, 1946, p. 315).

If a person takes a deep breath, he inspires 80% VC (Craig, 1965, p. 296). Therefore, when the subject in this experiment took a deep breath and produced 20 cm H_2O

pressure, there was little change in the heart rate because intrapleural pressure was zero. The 20 cm H_2O pressure were produced by the elastic rebound of the lungs. When the subject produced 40 cm H_2O pressure following a deep inspiration, 20 cm H_2O pressure were produced by the lungs and the additional 20 cm H_2O pressure were produced by change in the intrapleural pressure, so that intrapleural pressure was +20 cm H_2O (Craig, 1965, p. 296). Therefore, the heart rate response was greater for a 30-second breath hold at 40 cm H_2O pressure than for a 30-second breath hold at 20 cm H_2O pressure. (Figures 1 and 2, p. 27 and 28).

Figure 2 illustrates that sustaining a pitch for 30 seconds, which requires 40 cm H_2O pressure, produces similar pulse rate changes to those changes during breath hold at 40 cm H_2O pressure.

In this study there was no difference between pulse rate responses of wind players and control subjects. This could indicate that 40 cm H_2O pressure during wind instrument performance does not create sufficient stress to produce adaptation. If this is true, pulse rate responses to a 30-second breath hold producing 60 cm H_2O pressure may produce different results. However, it is possible that there is stress during wind instrument performance which does not produce adaptation.

This study does, however, demonstrate a difference in pulse rate responses of males and females. Borgia (1975, p 697) reported significantly greater incidence of cardiac arrhythmias in female French horn players than in males. However, results of the current study indicate that for the female, pulse rate is not as greatly affected, during breath hold at a positive pressure, as is the pulse rate of the male. Further investigation of cardiovascular responses of males and females may offer explanations for these differences.

APPENDIX

CONSENT FORM

DATA RECORD SHEET

University of Rochester
Rochester, New York

CONSENT FORM

Respiratory and cardiovascular function in musicians.
Principal Investigator: Albert B. Craig, Jr., M.D.

I, ________________________________, agree to participate in studies designed to learn the lung volumes, maximal breathing pressures, and responses of the heart rate to breath holding in musicians.

The procedures and the equipment have been explained to me and I understand that the methods are routine and well tested.

I understand that so far as known these procedures have no significant risk. I understand that some subjects may feel very slightly "light-headed" for a few seconds after developing positive breathing pressure and that this is considered to be inconsequential. Theoretically, it is possible, but highly unlikely, that developing maximal pressure could rupture a blood vessel if it is for some unknown reason weak at some point. However, the remote risk of this happening is probably no greater than when one is pushing a car or playing a "high A" on a trumpet.

So far as I know I am in good health at present and I have had no significant illness involving the heart, lungs, or blood vessels in the last five years.

I understand that as a subject I can freely stop the experiments at any time for any stated or unstated reason.

The contents of this consent have been fully explained to me, I have been offered the opportunity to make inquiries, and they have been answered to my satisfaction.

Question asked: ________________________________
Answer given: ________________________________

Question asked: ________________________________
Answer given: ________________________________

The procedures to be employed in this research activity by Dr. Craig have been described to me by Jane Middlesworth.

Subject's signature: ______________________________

Date: ______________________________

Witness: ______________________

Date: ________________________

Name: ______________________ Age: ________ Sex: M F Date: ________

Ht: ____________ Wt: ____________

Instrument: ____________________ Regular Exercise: ________________

P_B ____________________ Temp: ______________

	Trial #1	Trial #2	Trial #3	Final Value	
Peak flow rate					max
FEV 1 sec					
V.C.					max
FEV 1 sec%					ave
E.R.V.					ave
V.C.					max
			(ERV/V.C.)100		%
			V_T		
			f		
			$\dot{V}_E$		
			$\dot{V}_{O_2}$		
			$\dot{V}_E/\dot{V}_{O_2}$		
Max. exp. pres.					max

Heart rate response to breath holding

C	0 5	5 10	10 15	15 20	20 25	25 30	0 5	5 10	10 15	15 20	20 25	25 30	30 35	40 45	45 50	50 55	55 60
#1 20																	
#2 20																	
#3 20																	
ave.																	
#1 40																	
#2 40																	
#3 40																	
ave.																	

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