INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6” x 9” black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
THE CORRECTION OF FAULTY FINGER COORDINATION
IN BASSOON PLAYING: TRADITIONAL APPROACHES
AND A NEW DIAGNOSTIC TOOL

by
Carol Sue McNabb

A Document Submitted to the Faculty of the
SCHOOL OF MUSIC AND DANCE
In Partial Fulfillment of the Requirements
For the Degree of
DOCTOR OF MUSICAL ARTS
WITH A MAJOR IN PERFORMANCE
In the Graduate College
THE UNIVERSITY OF ARIZONA
1996
As members of the Final Examination Committee, we certify that we have read the document prepared by Carol Sue McNabb entitled *The Correction of Faulty Finger Coordination in Bassoon Playing: Traditional Approaches and a New Diagnostic Tool* and recommend that it be accepted as fulfilling the requirements for the Degree of Doctor of Musical Arts.

Dr. William Dietz  

Prof. Jerry Kirkbride  

Prof. Warren Sutherland

Final approval and acceptance of this document is contingent upon the candidate's submission of the final copy of the document to the Graduate College.

I hereby certify that I have read this document prepared under my direction and recommend that it be accepted as fulfilling the requirement.

William Dietz  

Director  

7/12/96
STATEMENT BY AUTHOR

This document has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under the rules of the Library.

Brief quotations from this document are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Carol Sue McNabb
ACKNOWLEDGMENTS

This lecture document would not have been possible without the immeasurable support and understanding that I have received from my parents, friends, colleagues, and professors. I especially thank my father, Robert E. McNabb, for bringing the idea for the Bassoonist's Coordination Measurement System to reality through his design work, construction, and computer programming.

I would like to thank my parents and Dr. Roger Jones of Northeast Louisiana University in particular, for encouraging me to pursue my doctorate.

I would like to thank Sandra Sasarita, hand therapist at University Medical Center Hand Clinic, and James Terlep, occupational therapist at University Medical Center, both in Tucson, Arizona, for sharing their extensive knowledge of arm and hand physiology.

I extend my thanks and gratitude to the members of my doctoral committee and Dr. Robert Clifford for monitoring the progress of my degree and supporting me through the final stages.

I am greatly indebted to and extend my sincerest gratitude to Dr. William Dietz for his guidance and assistance throughout the duration of this lecture document and my tenure at The University of Arizona.
DEDICATION

This document is dedicated with love and gratitude to my parents, who because of their love of music always provided me with the best music teachers and instruments possible. I thank them for their understanding and encouragement, without which I never could have come to this point.
# TABLE OF CONTENTS

| LIST OF TABLES | 8 |
| ABSTRACT | 9 |
| I. INTRODUCTION | 10 |
| II. WHY BASSOON FINGERING IS SO COMPLEX | 12 |
| - Use of the Thumbs | 13 |
| - Use of the Little Fingers | 16 |
| - Additional Problems | 16 |
| - Categories of Finger Movements | 17 |
| - Level of Fingering Difficulty | 18 |
| III. A BRIEF HISTORY OF MOVEMENT ANALYSIS TECHNIQUES | 20 |
| - Motion Pictures | 21 |
| - Videography | 22 |
| - Electromyography | 22 |
| - Computer Simulation | 23 |
| - Force Plates | 23 |
| IV. EXPERIMENTS IN MOVEMENT ANALYSIS | 25 |
| - Recent Experiments in Movement Analysis pertaining to Adult Musicians | 25 |
| V. THE PHYSIOLOGICAL BASIS OF MOVEMENT | 29 |
| - Motor Skill and Motor Ability | 31 |
| - Systems of Movement Categorization | 31 |
| - How Movement Occurs | 32 |
| - How the Brain Directs and Monitors Movement | 33 |
| - Hand Structure | 34 |
| - Types of Feedback | 37 |
| - Motor Programming | 38 |
| | 39 |
| - Motor Programming Strategies in Music | 42 |
| VI. TRADITIONAL STRATEGIES FOR IMPROVING FINGER COORDINATION | 44 |
| - Scale Practice | 44 |
| | 47 |
| - Selected Practice Strategies | 50 |
| - Physical Strategies | 51 |
| - Mental Strategies | 58 |
| VII. BASSOONISTS’ COORDINATION MEASUREMENT SYSTEM | 63 |
| - Design and Development | 63 |
| - Components | 65 |
| - Analysis of Data | 67 |
TABLE OF CONTENTS—Continued

Results, Conclusions, and Recommendations for Further Study ............... 76
VIII. DISCUSSION OF FANTASY FOR BASSOON BY MALCOLM ARNOLD ...... 80
APPENDIX A, DIAGRAMS FOR THE BCMS ........................................... 87
APPENDIX B, BCMS PROGRAM LISTING ............................................... 90
APPENDIX C, FINGERINGS FOR INTERVALS TESTED WITH THE BCMS .... 103
REFERENCES .......................................................................................... 106
LIST OF TABLES

Sample Table Line, d$^c^\#$ .......................................................... 68
Table 1A, B$^{\uparrow}$d ................................................................. 69
Table 1B, d$^{\downarrow}$B ............................................................... 70
Table 2A, f$^{\uparrow}$g ................................................................. 70
Table 2B, g$^{\uparrow}$f ................................................................. 70
Table 3A, f$^{\uparrow}$f ................................................................. 71
Table 3B, f$^{d \downarrow}$f ............................................................... 71
Table 4, B$^{b \uparrow}$A$^{b}$ ............................................................. 72
Table 5, B$^{b \downarrow}$ alternate G$^{b}$ ............................................... 72
Table 6A, c$^{\# \uparrow}$d ............................................................... 72
Table 6B, d$^{\downarrow}$c$^{\#}$ ........................................................... 73
Table 7A, c$^{\# \uparrow}$d$^{\#}$ ........................................................... 73
Table 7B, d$^{\# \downarrow}$c$^{\#}$ ........................................................ 73
Table 8A, d$^{\uparrow}$e$^{b}$ ............................................................. 74
Table 8B, e$^{b \downarrow}$d ............................................................. 74
Table 9, c$^{\uparrow}$a ................................................................. 75
Table 10A, g$^{\uparrow}$a$^{\prime}$ ......................................................... 75
Table 10B, a$^{\downarrow}$g$^{\prime}$ ......................................................... 76
ABSTRACT

This document examines the issue of correcting faulty finger coordination in bassoon playing and describes the development and use of a diagnostic device which allows the player to determine precisely what finger(s) is out of synchronization with the others in transitions from one note to the next.

A brief history of movement analysis techniques is given, and several studies of the finger movements of adult musicians which used various types of technology are discussed.

In order to understand how movements occur, basic physiological information is provided about the brain, the forearm, the wrist, and the structure of the hand. Included is a discussion of motor programming as related to learning the complex sequence of movements involved in playing a piece of music on an instrument.

Traditional strategies for improving finger coordination which are applicable to the bassoon have been selected from other woodwind resource books and articles. Mental strategies are also discussed, taken from the fields of "Inner Game" theory, sports psychology, and movement efficiency training.

A description of the performance difficulties found in Fantasy for Bassoon, op. 86 by Malcolm Arnold concludes the study.
I. INTRODUCTION

One of the more difficult aspects of bassoon playing is mastering the complexities of finger coordination. The author's interest in her personal technical development, as well as the pedagogical aspects to the problem have been of interest for many years. Faulty finger coordination may be difficult to correct because before one can devise a strategy to correct the problem, one must first discover exactly where it occurred in a passage, then discern which finger was at fault, and finally ascertain why the finger did not move properly.

The ear is the only guide to pinpointing the location of faulty coordination and often a tape recorder can be a great benefit in this process. While listening to the tape we are freed from concentrating on making the movements and can pay closer attention to listening for the problem. Once located, we must precisely determine the nature of the technical problem. Was a finger late rising or pressing in relation to the others? Is there a combination of fingers that are not synchronized? The device developed in connection with this project is an accurate method for determining the precise nature of the finger problem.

Once we know what finger is at fault, we can ask why it did not move properly. Was it a case of unnecessary muscle tension, poor balance of the instrument, hands being out of position from a previous finger movement, lack of clarity in the mind as to
the sequence of notes, or even self-doubt that we could play the passage? Once we have progressed completely through the analysis of the problem we can devise a successful practice strategy.

The subject of finger coordination in playing a woodwind instrument therefore involves the exploration of several diverse areas: movement analysis techniques, physiology, psychology, motor programming, as well as both physical and mental practice techniques. This paper intends to interrelate these disciplines in an effort to shed light on the various methods for improving finger coordination in bassoon playing. As a result of her research, the author has made several changes to her playing, and hopes that the reader may find something useful as well.
II. WHY BASSOON FINGERING IS SO COMPLEX

Unlike the fingering systems of the other modern woodwind instruments, the fingering system of the bassoon has never been successfully reworked. Attempts at redesigning the bassoon, made in the mid-nineteenth century by Charles and Adolphe Sax, Ward and Tamplini in London, and Boehm had the unfortunate result of drastically altering the characteristic bassoon timbre.¹

However, a few innovations have been widely accepted. A trend in bassoon manufacture has been to provide options for extra keys for specialized circumstances, customized key shape and positioning of keys on the instrument, as well as options for rollers between certain keys to make finger movement from one to the other easier. An example of a specialized key is the $A^b$ to $B^b$ trill key, located on the boot joint and operated by the right thumb. Some players feel that this gives them a trill which is better in tune and easier to perform than the standard trill fingering. This trill is prominent in Mozart's *Concerto for Bassoon*, K. 191, which perhaps explains the popularity of this key.

Gheorghe Cuciureanu, bassoon professor of the Music Academy in Bucharest, Rumania, has devised special keywork for the bassoon to make certain fingering changes less awkward. The Cuciureanu System includes an extra pair of keys on the

right thumb for the low notes normally fingered by the left thumb, automatic opening and closing of the E\textsubscript{b} and D\textsubscript{b} keys normally fingered by the left little finger, a trill mechanism for E to F\# which eliminates the sliding movement of the right thumb, and an articulated A\textsubscript{b} to B\textsubscript{b} trill allowing the right fourth finger to make the trilling movement while the B\textsubscript{b} key is held by the right thumb. Although the Fox Bassoon Company began offering this system as an option in 1981, it has yet to be widely accepted.\textsuperscript{2}

Use of the Thumbs

In bassoon playing, the thumbs are used to a much greater extent than on the other woodwind instruments. The left thumb has nine keys to operate on most professional model bassoons, including keys used in producing the low register of the bassoon, located on the long joint of the instrument. For certain notes, more than one key is depressed by the left thumb, as is the case for c\textsuperscript{#}, in which three keys must be held. The four keys for the low notes are for D, C, BB, and BB\textsubscript{b}. The addition of the left little finger produces the C\textsuperscript{d} and D\textsuperscript{#}.

The left thumb is also used for producing the correct octave of notes which otherwise have the same fingering in two different octaves. These notes are A and a,

There are four keys on the bassoon's wing joint which are used in producing the desired octave. The lowest of these, the "whisper key" is held down to close the hole in the bocal, allowing the lower octave notes to sound. It is used for the notes F up to a\textsuperscript{b}. To produce the desired octave for the notes f\textsuperscript{#}, g, and a\textsuperscript{b}, an additional specialized technique is required, that of partially opening the hole covered by the left index finger. This technique is known as "half-holing." Although the oboe also requires half-holed notes, for which a key with a center hole is provided, the half-hole technique on the bassoon is more difficult because it is necessary to open slightly different amounts of the tone hole for the three different pitches. Bassoons have been manufactured with a half-hole key similar to the oboe's (notably those made by the Polisi Corporation) but such a key only marginally allows for the opening of different amounts of the hole.

To assist in initiating the higher octave notes of a, b\textsuperscript{b}, b, c', and d', there are the "flick keys" located above the whisper key, also operated by the left thumb. There may be either two or three of these keys, with three generally present on professional-model bassoons. These keys are lightly tapped, or flicked, when slurring from f or below up to these notes, or in certain difficult down-slurs from notes above them. The remaining left thumb key is the c\textsuperscript{#} key, located just above the whisper key. The left thumb must roll upwards to depress it for both c\textsuperscript{#} and c\textsuperscript{##}. For the lower octave, the thumb must
hold down the whisper key in addition to the c⁰ and low D keys, but for the higher octave, the thumb must release the whisper key. The flick keys and the c⁰ key are also used in producing notes of the bassoon's high register.

The right thumb has four keys which it must operate, located on the boot joint of the bassoon. These keys are primarily used for the notes Bᵇ, bᵇ, E, F⁰, F⁰, Aᵇ, and aᵇ, but they are also used for other purposes, such as for improving the intonation of other notes on the instrument and for high register playing. The low E key is also known as the "pancake key" due to its large size, necessary to close the large tone hole directly underneath it. It must be held closed for all notes from E down to the bassoon's lowest note, BBᵇ.

If we compare the bassoonist's left thumb responsibilities to that of the other woodwinds, we find that the clarinet has a hole to be covered and a high register key, the oboe has an octave key (some models have two of them), the flute has two keys, and the saxophone only an octave key. None of the other woodwinds are nearly as complicated as the bassoon in the use of the left thumb. Furthermore, none of the other woodwinds use the right thumb at all for anything other than supporting the instrument.
Use of the Little Fingers

The bassoon also has keys for the left and right little fingers to operate. There are two for the left little finger and three for the right little finger. The oboe, clarinet, and saxophone actually have more of these keys than the bassoon, but they have duplicate keys for certain of their notes, for example, the alternate $e^b$ keys for the left and right little fingers on the oboe. In the case of the bassoon, the alternate fingerings are not duplicated for the little fingers but are between the right thumb and the right little finger, for the notes $F^b$ and $A^b$.

Additional Problems

An additional difficulty in bassoon finger coordination is that in some instances a finger or a thumb must begin to move earlier than the other fingers to change to certain notes. This is the case in the flicking technique, as described above, in which the left thumb must leave the whisper key early in order to reach the flick key when the rest of the fingers change to the new note.

In addition to the difficulty described above for the normal fingerings (themselves often extremely complicated), the bassoonist must make use of a large number of alternate fingerings for reasons of ease of fingering in fast passages, needed pitch alterations, control while playing at soft dynamic levels, and timbre choices. The recognized standard collection of bassoon fingerings is a complete book of over 300
pages, *Essentials of Bassoon Technique*, by Lewis Hugh Cooper and Howard Toplansky. An indication of the complexity of bassoon fingerings is the statement by the authors in their preface, “Under normal circumstances, a maximum of five or six fingerings for a given pitch is all that is necessary for any player to master most technical passages.” This means that there are many combinations of fingerings which must be mastered.

**Categories of Finger Movements**

There are several types of finger movements in woodwind playing that are used when changing from one note to another. Fingers may directly close or open tone holes, or they may press or lift from keys. Keys work in two ways: pressing can open a key (lifting would close it) or pressing can close a key (lifting would open it). The various types of finger movements may be broken down in a general hierarchical level of difficulty as follows, with examples on the bassoon:

1. Simple lifting or pressing of one finger, for example, c to d

2. Simple lifting or pressing of two or more fingers of the same hand, at the same time, for example, c to e

---

3. Lifting or pressing one or more fingers of one hand in coordination with the lifting or pressing of one or more fingers of the other hand (all fingers lifting or all fingers pressing), for example, B to d.

4. Lifting a finger of one hand while pressing a finger of the other hand (the finger exchange or “swap” between hands), for example, g to a^.

5. Lifting or pressing a finger while another finger of the same hand moves in opposition (the finger exchange or “swap”), for example, d to e^ (simple fingering without additional keys to stabilize intonation).

6. Combinations involving the thumbs, for example B^ to d^.

7. Any other combination of lifting or pressing fingers involving the fingers and/or the thumbs moving in opposite directions in both hands, for example g’ to a’.

Level of Fingering Difficulty

In *The Art of Wind Playing*, author Arthur Weisberg, a bassoonist, has assigned numerical values relating to the level of difficulty of the fingering changes in the famous bassoon solo in Ravel’s *Bolero*. He explains that a player may be capable of changing perfectly between any two notes, but that in a fast passage, the fingers may not reach their proper positions at the same time. This causes the next note to be uncertain. He
suggests that it is the constant change in the level of coordination skill needed when moving from note to note that makes the passage so difficult. 4

III. A BRIEF HISTORY OF MOVEMENT ANALYSIS TECHNIQUES

The study of human movement may be considered a sub-field of psychology in that it is the study of a type of human behavior, in this case, physical behavior. Studies and experiments have been conducted covering many types of human physical behavior including typing, Morse code, sports applications of many kinds, as well as abstract tasks such as mirror tracing. Recently, a number of experiments have been undertaken to study the movements of musicians. The data obtained from such studies can provide clues about learning and practice conditions which will allow the subject to improve the quality and/or the speed of the specific movement.

Early attempts to analyze human movements were hindered by the lack of appropriate measurement devices. Visual observations were lacking in precision. With the development of instantaneous photography and cinemaphotography, a major breakthrough occurred. Beginning in the 1860s, studies were made by Eadweard Muybridge (1830-1904) in the United States, Étienne-Jules Marey in France, and Braune and Fischer in Germany. The work of Muybridge consisted of photographs at closely timed intervals of the motions of humans and animals. His series of photographs of a galloping horse, made in 1872 by using twelve cameras operated by trip wires, was used to prove that all four feet of the animal could be off the ground at

---

the same time. The pictures were mounted to a revolving drum, allowing the viewer to watch the movement. Marey developed the technique of recording images on strips of sensitized paper and paper-backed celluloid in 1889, the same year that the Eastman company began to produce roll film.

Motion Pictures

These developments set the stage for the invention of the motion picture camera, generally credited to Thomas Edison in 1889, although his genius was more in combining the discoveries of others. Coordinated film and sound were developed during the 1920s. With the motion picture camera, complex sequences of movement could now be filmed and analyzed much more easily. Film could be shown not only at slower speeds than the actual motion took place, but each frame could even be frozen and analyzed. Furthermore, filming for movement analysis could take place without the equipment having to be attached to the subject and without the subject being aware that filming was taking place.

---


7 "Motion Pictures" 418.

8 "Motion Pictures" 418.

9 Grieve 4.
Videography

The development of the video camera provided a further possibility for recording visual images of movement. Like motion picture filming, videography provides the capability of freezing motion and of displaying motion at slower speeds, but because no film developing need take place, immediate replay is possible, which can be highly beneficial to the subject. Immediate feedback is an important part in motor learning because the subject can make corrections while the kinesthetic sense of the movement is still fresh in the mind.

Electromyography

Movement may also be analyzed by non-visual methods. The field of medicine has provided a number of useful analysis tools, including electromyography. Electromyography is the process of recording the electrical activity of the muscles, by placing a flat metal plate on the skin over the muscle to be tested, then inserting a needle into the muscle, attached by wires to a recording machine. A record is made of the fluctuations of potential, or voltage, that occur between the two conducting metal surfaces.\(^{10}\) The electrical activity appears as waves on an oscilloscope and is

\(^{10}\) Grieve 110.
reproduced at the same time as sound through a speaker. Electromyography shows when the muscles are active as well as when they are at rest.\textsuperscript{11}

\textbf{Computer Simulation}

Another non-visual tool is that of computer simulation, which came into wide usage in the late 1960s.\textsuperscript{12} It is often employed for answering "what if" questions, such as what would be the result if a person applied more force to an object, what if the angle of the movement was changed, or what if the speed of the movement was changed.\textsuperscript{13} A computer program calculates factors such as distance and speed, based on the data which is entered. This method of movement analysis has been used in many sports applications, such as the golf swing, diving, swimming, shot putting, and weight lifting.

\textbf{Force Plates}

Various devices have been developed to measure the amount of force which a walking person applies to a metal plate. These are often called dynamometers. One example of their use is the measurement of the amount of force exerted by the feet of


\textsuperscript{12} Grieve 100.

\textsuperscript{13} Grieve preface.
patients before and after hip surgery. An early example of such a device dates from 1916, when it was used to improve the design of artificial limbs.\textsuperscript{14}

\textsuperscript{14} Grieve 161.
IV. EXPERIMENTS IN MOVEMENT ANALYSIS

Movement analysis has over a one-hundred-year history. Some of the earliest experiments in the field focused on such skills as Morse code and typing. These often attempted to determine optimum practice conditions for learning a motor skill. Many of the early findings are still of use to musicians. However, there remain many unanswered questions.

There have been a number of experiments on children's development of gross motor skills in connection with music. For example, a study by J. P. Gilbert measured the development of mallet-striking skills necessary to play percussion instruments, in which 800 children between the ages of three and six were tested.\textsuperscript{15} Although it is important that these large-scale musical motor skills be developed at an early age in order for a person to mature into a successful adult musician, these studies are not of importance to the topic of this paper.

Recent Experiments in Movement Analysis pertaining to Adult Musicians

There have also been some studies involving the motor skills of adult musicians. A summary of those which involve finger coordination follows.

A project developed by W. H. Tucker, et al in 1977, utilized a digital synthesizer in connection with real-time computerized displays of music being played at the keyboard. The display, which was remarkably similar in appearance to a the piano roll, consisted of bars of various lengths, corresponding to the length of time each note was held, positioned on the line or space for the note in the staff. Using the system, a performer could recognize and correct faulty technique, as in the case of a concert pianist who was able to correct a faulty triple-trill.  

In another keyboard-related experiment, a piano was equipped with sensors which detected the position of each key (either up or down) and recorded the duration of each note and the interval of time before the next note. The data was examined for evidence of “chunking” or grouping of keypresses by the performer. The device developed in connection with this paper utilizes the same principle of reading a switch position and recording the length of time until it changes to a new position.  

Another experiment used the video camera to record the movements of pianists. Adhesive, paper dots were attached to each player’s upper arm, elbow, wrist and little finger. The player was videotaped while playing and the position of the dots was processed into digital form by a computer, sampled slightly faster than every quarter-second. Stick-figure images could then be produced showing the angles of the arm and

---

hands. These could be analyzed in connection with the sound to determine what type of movement produced each type of tone quality and attack.\textsuperscript{18}

A study by Gary Callahan is quite similar to the topic of this paper. In his dissertation, "The Measurement of Finger Dexterity in Woodwind and Brass Instrumentalists: A Developmental Study," Callahan modified a trumpet and a clarinet by equipping them with miniature switches which registered finger positions. In the case of the clarinet, selected keys were removed from the instrument and the switches were mounted from inside the bore. He tested undergraduate students enrolled in brass and woodwind methods classes on their ability to accurately perform various patterns of two and three notes. Callahan found that on the clarinet, one of the most difficult types of movement was that which involved the left thumb.\textsuperscript{19} This finding substantiates the writings of Rosario Mazzeo in his book, \textit{The Clarinet: Excellence and Artistry}, in which he voices his opinion that the thumb movements are among the most difficult coordination problems on the clarinet.\textsuperscript{20} This finding is of particular interest to the bassoonist because of the large number of keys that the left thumb must operate. Because the clarinet has no keys for the right thumb to operate, there was no


comparison of the relative difficulty of accurate coordination between the player's right and left thumb.
V. THE PHYSIOLOGICAL BASIS OF MOVEMENT

Particularly in the areas of violin and piano performance, writers have sought to provide physiologically-based justification for specific types of movement they have advocated. As early as 1903 scientific investigations of violin bowing technique began to be made. These have addressed such issues as how the weight of the bow is transferred through the arm and fingers to the strings of the violin, the relative importance of the thumb versus the fingers in the bow hold, and the involvement of other body motions (such as inhalation) in the bow stroke. However, many unanswered questions about bowing remain.21

In the field of piano pedagogy, Otto Ortmann scientifically studied the movements of advanced pianists through photography, first publishing his work, The Physiological Mechanics of Piano Technique, in 1929. Although other writers described what they considered proper movement technique for pianists, few were as scientifically based as Ortmann’s.22 Recently researchers have begun to study the movements of pianists with more sophisticated technology.

This type of physiological background is rare concerning efficient finger movement in woodwind playing. In contrast, many woodwind books contain precise


explanations or diagrams of the muscles used in breathing. An example of this may be found in the first volume of *Fagott-Schule*, the extensive, six-volume work by Werner Seltmann and Günter Angerhöfer. Numerous writers have also sought to explain in medical terms how woodwind players produce vibrato, for example, Arthur Weisberg in *The Art of Wind Playing*, Seltmann and Angerhöfer, and others. None of these important source materials for bassoon pedagogy has a physiological description of finger movements.

It is this writer's intention to provide an overall view of the body mechanisms involved in moving the fingers. The discussion will include the anatomy of the fingers, hand, wrist, and arm, and a description of the way in which the brain directs the finger to move. It will not, however, include a discussion of the electrochemical processes involved at the cellular level.

Some of the questions that this study seeks to answer are as follows:

1. Is there a medical basis to support that the most controlled movement of the finger should originate from the first joint (knuckle)?
2. Are straight wrists conducive to freer finger movement?
3. Is finger control lost by backward flexing of the last joint of the finger?

---


Concluding the chapter is a discussion of the concept of motor programming, the method by which complex movements are learned and remembered.

**Motor Skill and Motor Ability**

There are many different types of skilled human movement. The terms “motor skill” and “motor ability” may be differentiated as follows. A motor skill may be defined as “the consistent degree of success in achieving an objective with efficiency and effectiveness.”^25 It can be described in terms of speed, accuracy, efficiency, and adaptability. A motor ability is a “general trait that contributes to success in the performance of a number of skills.”^26

**Systems of Movement Categorization**

One of the most widely accepted categorizations of motor abilities, first proposed by E. A. Fleishman in 1967, divides motor abilities into two domains: the gross motor and the psychomotor. The gross motor domain consists of nine types of abilities including four distinct types of strength (such as endurance), two types of flexibility (such as total range of motion of a joint), gross body coordination, gross body equilibrium, and cardiorespiratory endurance. The psychomotor domain consists

---


26 Singer 48.
of eleven types of abilities such as reaction time needed to respond to a stimulus, and aiming or eye-hand coordination, as well as three skills of special importance to musicians: manual dexterity, finger dexterity, and wrist-finger speed. Eye-hand coordination would also be important if the musician were reading music while playing, as opposed to playing by memory; however, a discussion of eye-hand coordination is beyond the scope of this report.

Another way to categorize movement is by whether it is paced strictly by the performer or by other people or moving objects, as would be the case in various sports. Playing a musical instrument can fall into both of these categories: if the person is practicing or playing alone, the movement is internally paced to a certain degree (the performer must still play the printed rhythms and take into consideration the composer’s tempo markings), but if a person is playing in an ensemble, the movement would be externally paced.

How Movement Occurs

Movement takes place because of muscle contraction. Skeletal muscle (as opposed the muscles of the organs) is attached to the bones and joints and is responsible for movement of the torso, limbs, fingers, and so forth. A muscle is made up of many muscle fibers which can contract individually or along with other fibers of

---

the muscle. The nerve carries an impulse to the muscle, causing a chemical reaction to occur which releases stored energy, making the muscle fiber shorten or contract. If the nerves deliver their impulses to a large number of the muscle fibers, the movement is more forceful. Almost immediately after the contraction has taken place, another chemical reaction occurs which allows the muscle to relax. Muscles are arranged inside the body in pairs, called agonists and antagonists. When one pulls, its partner relaxes to make the movement easier.  

How the Brain Directs and Monitors Movement

Once a movement is planned, a series of coded signals begins in the brain’s basal ganglia (cell groups that regulate the cooperation of groups of muscles and body position) and motor strip. The motor strip runs across the top of the brain from ear to ear. Through the use of mild electrical stimulation, scientists have mapped the motor strip, revealing that some of its largest areas are devoted to controlling movements of the face, tongue, mouth, and hands. Signals are relayed from there to the anterior horn cells of the spinal cord which activate the appropriate muscles. Sensing mechanisms, called proprioceptors, are embedded in the muscles and serve to collect information as to the degree muscles are contracted, the amount of tension in the tendons, and the

---

change of position in a joint. As the muscles begin to move, the nerves in them, as well as those in the skin (and the eyes if the movement is being watched) relay progress reports back to the cerebellum. This is commonly known as feedback. One of the roles of the cerebellum, located under the hemispheres of the brain, is to monitor the action of the muscles and to direct adjustments or corrections in the movement as it progresses. In addition to these complex parts of the brain, each muscle has muscles spindles which act as a self-contained reflex subsystem that can act on the anterior horn cells. In this way, the muscle can make quick adjustments.

Hand Structure

The hand muscles are activated through the three major nerves of the arm, which are the radial nerve, the median nerve, and the ulnar nerve. Some of the muscles that control the action of the fingers are located not in the hand, itself, but in the forearm. These power the opening and closing of the fingers. The muscles that are located in the hand are those used in making fine, coordinated movements that do not

---


30 Wilson 47.

require great force. In all, there are 78 muscles involved in moving the wrist and fingers of each hand.\textsuperscript{32}

There are many bones involved in movements of the hand. The bones in the forearm are the radius and the ulna. There are eight bones in the wrist, called the carpal bones, arranged in two rows. This configuration allows the wrist to be bent from side to side. In the palm of the hand are the metacarpal bones—one for each finger and the thumb. These meet the bones of the fingers, called the phalanges. Each finger has three of these bones, while the thumb has only two.\textsuperscript{33}

As Sandra Sasarita, a hand therapist at University Medical Center Hand Clinic in Tucson, Arizona, explained, certain movements are more difficult to make than others because of the muscle structure of the forearms and hands. The index finger and the little finger have extra muscles that make them more independent than the other fingers. In fact, the little finger has a special abductor muscle that pulls it from side to side. This movement is often necessary on the bassoon due to the multiple keys the little fingers operate. Due to interconnections on the back of the hand between the fingers, the ring finger is more limited in movement than the other fingers.\textsuperscript{34} Generally the muscles that lift a finger (the extensors) are weaker muscles that those that press a


\textsuperscript{34} Sandra Sasarita. Interview. 20 July 1995.
finger down (the flexors). This is the likely explanation for lifting movements being less accurate than pressing movements. Also the muscles that raise and lower the fingers at the knuckle originate in the forearm and are more powerful than the smaller muscles intrinsic to the hand that are at their best for finer movements. The downward movement of the finger from the first phalange (knuckle) is the most powerful, which provides a reason for initiating finger movements from this joint.³⁵

There is also a physiological reason basis for playing with the wrists in a straight alignment with the forearms and palms. Bending the wrist decreases the power of the flexor muscles of the fingers. It also prevents adequate nourishment to the median nerve, which can lead to numbness. Unnecessary tension in the forearm is also detrimental to optimum finger movement because blood flow to the muscles would be impeded, leading to fatigue.³⁶

The angle of the left index finger is in a less than optimum position for good coordination. Because of its role in balancing the bassoon, this finger must be hyperextended (bent slightly backwards). The muscles do not work at their greatest efficiency at this angle.

There is also a physiological reason for playing with good posture and with a proper chair in order to improve finger coordination. According to James Terlep, an

³⁵ Sasarita.
³⁶ Sasarita.
occupational therapist at University Medical Center in Tucson, Arizona, "hand function starts at the spine." He explains that using extra muscles to remain seated in a chair of improper slant or height quickly leads to excess tension throughout the body.\textsuperscript{37}

**Types of Feedback**

As is the case in learning any type of movement, feedback is of great importance to the musician. Feedback compares the action with the desired goal and detects errors; this information is then used for subsequent correction of the movement.\textsuperscript{38} The most obvious type of feedback is the auditory type, or what the music sounded like. Only by critically listening to one’s own playing is there the chance to improve it.

Another type of feedback comes from the muscles. The proprioceptors, as defined above, monitor the position of the muscles and relay this information to the brain. Feedback may also be visual, with the eyes tracking the progress of the movement. One of the problems in playing certain musical instruments, such as the bassoon, is that the hands are not in a position to be visible to the performer. In this case there is no visual feedback, only proprioceptive and auditory.

\textsuperscript{37} James Terlep. Interview. 20 July 1995.

\textsuperscript{38} Kleinman 49.
Motor Programming

Because movements of the fingers must often occur at such a high speed in certain activities, such as playing a musical instrument, there is often not enough time for messages to be relayed from the muscles to the cerebellum and back to the muscles to correct the movement before the next movement must begin. This type of movement was confirmed in 1895 by Paul Richer through the study of a series of rapid-sequence photographs of the quadriceps muscle during a kicking motion. He noticed that the muscle contraction launched the limb and ceased before the movement was completed. Because this is similar in nature to the firing of a gun shell, it was given the term, "ballistic."\textsuperscript{39} Some studies have provided evidence that a sequence of movements may be learned and stored in long-term memory as one unit in order to be retrieved and performed at high speed without the brain monitoring each component of the sequence. This is called motor programming. Movements that are slow enough to allow correction upon the reception of feedback are known as closed-loop, while movements that are over before feedback can be used to make corrections are known as open-loop.

There is much debate over how motor programs are actually represented in long-term memory. A useful analogy may be found in cybernetics (a way of thinking about human behavior by relating it to computers). In computer programming, frequently used procedures are often written only once into the program and when execution of them is needed, the main program calls them by name to run them. These

\textsuperscript{39} Wilson 49.
sub-sections of the main program are known as "subroutines." A group of individual movements may come to be stored together in the memory as a subroutine which is called up to be executed as a whole when needed. This is most likely the way skilled typists produce common words quickly. Others have termed this grouping of a set of movements "chunking" and there is evidence that it occurs in playing a musical instrument, especially in sight reading. If while reading music, a scale pattern that has been well ingrained in the player’s technique is recognized and performed adeptly, it is likely that chunking is responsible.

Stages of Learning a Motor Skill

How does a person learn a complex series of movements, be it an athlete, a worker learning a specialized skill, or a musician? Paul Fitts, writing in 1965, proposed three stages of learning a motor skill: the initial cognitive phase, the intermediate or associative phase, and the final or autonomous phase. In the initial phase, the subject learns the goal of the task, the movements that will be necessary, and the best strategy for achieving the desired results. In the associative phase, movements become organized into well-coordinated patterns, and timing becomes fixed. The motor program gradually develops at this stage. In the autonomous phase, movements

---

become automatic, the motor program becomes longer to include a larger sequence of movements, and thought about each component movement stops.\footnote{George H. Sage, \textit{Motor Learning and Control}, (Dubuque, IA: William C. Brown, 1984) 376.}

\textbf{Cognitive Stage.} How should one approach the task of learning a piece of music initially? Referring back to Fitts' stages of motor learning, in the cognitive stage, the musician must develop a clear understanding of the desired performance; he or she must work out the rhythms and fingerings with care. If there is a choice of fingerings, one should be chosen at the beginning of practice on the passage. If fingerings are changed later, there is always a chance that in the actual performance, the previous fingering will reappear and cause an error to occur. Each change from note to note must be perfectly mastered (which has often already occurred in the course of daily scale studies and other technical exercises) with a minimum of motion of the fingers and hand. Some changes from one note to the next note will initially be more difficult than others, but they must be mastered equally well. This is the time to insure that the fingers are rising no higher than necessary, that the fingers are staying over their proper keys, and that no unneeded wrist movements are occurring. Also important is to monitor one's muscles for constant relaxation. It is quite easy for tension to become established when it appears that something will be difficult to learn.

The next step would be to practice small groups of notes at a time, then to practice two groups together, and so forth, overlapping the sections until finally the
whole passage is learned. This is a way of utilizing the chunking capabilities of the brain. All of this practice should be done at a slow speed with the greatest possible accuracy.

**Associative Stage.** At the second stage of motor learning (Fitts’ associative stage), the timing of the movement is learned and the motor program begins to be developed. It is at this point that the metronome becomes a valuable practice tool. Because this device accurately sounds the pulse (or can be set to sound even smaller portions of it), the musician can use it to gradually increase the speed of practice of the passage in a very controlled manner. In this way proper timing of the passage is maintained. A common practice technique among musicians is to play the passage ten times in a row perfectly at a slow speed, then set the metronome to a slightly faster speed and play it again ten times in a row, and so forth, each day until the desired speed is reached.

**Autonomous Stage.** At the final stage of motor learning (Fitts’ autonomous stage), the motor program should be highly developed and the musician should be able to execute the passage correctly every time at the desired performance speed. The musician should feel that the passage has become automatic, and that he or she does not have to think about how to move at the most difficult parts. It is impossible to predict how long this will take each person to accomplish; however, it is not uncommon for musicians to work on important solo works for a year before publicly performing them.
Correcting a Motor Program

If the person cannot play the passage perfectly each time, some reprogramming will be in order. This may mean returning to slower practice speeds and insuring that tension is not hampering the movement. As with sports skills, it is much harder to correct a movement that has been learned incorrectly than to learn the movement correctly in the first place. If difficulties are not being caused by excess tension or faulty movement such as the fingers being out of their positions, some probable causes of difficulty might include sequence of events errors and timing errors. As in typing, when two letters are transposed in a word, in music, two notes may be inadvertently transposed in a passage. This is a sequence of events error. Slow, deliberate practice will often serve to correct it. If timing errors are discovered, in which the fingers are working unevenly, use of the metronome at a slow speed in connection with monitoring for relaxed muscles usually corrects this condition.

Motor Programming Strategies in Music

Given the knowledge obtained from numerous studies of how movement can be learned more efficiently, certain strategies would most likely help a musician who is trying to learn a fast and difficult section of a piece of music. In a number of experiments involving sport skills, it has been shown that distributed practice, as opposed to massed practice, produces superior performance. Any musician knows the
necessity of daily practice in learning a difficult passage of music, and that trying to learn a difficult passage at the last minute simply does not work.\textsuperscript{42}

Research has shown that practicing the movement in small components is the preferred strategy if the movement to be learned is complex. Related to this is the fact that the first and last components that were learned are usually learned the best. For this reason, the performer may find it useful to practice component parts starting with the most difficult. If both speed and accuracy are important to the performance, both should be emphasized in the practice.\textsuperscript{43}

Although there have been some studies of the movements of musicians, the body of research is much smaller than that for sports applications. A great deal remains to be done in this field to determine precisely what practice strategies work for musicians.


\textsuperscript{43} Singer 443.
VI. TRADITIONAL STRATEGIES FOR IMPROVING FINGER COORDINATION

In addition to the private instrumental teacher, books and articles on the various woodwinds are a rich source of suggestions for improving finger technique. Many of these techniques transfer well to the bassoon. Authors often recommend scale work, including scales in thirds and fourths in all major and minor keys. They may provide various rhythms in which to practice the material, and many stress the importance of working with the metronome for evenness of notes.

Scale Practice

The importance of scale practice for the improvement of finger coordination has been widely recognized and discussed in a number of books and articles on the various woodwinds. Clarinetist Larry Combs clearly summarizes the benefits of scales practice, explaining, "In much conventionally notated music, scales and arpeggios are the basic building blocks of melodic structure, and having these ingrained into finger patterns in a habitual way makes great facility possible."44

In Mazzeo's *The Clarinet, Excellence and Artistry*, the author defines mastery of the clarinet as the ability "to play every note over the entire register, in every nuance, with a variety of tone colors, at any speed, with any articulation, with every kind of

---

start and close, and with all changing gradations." He states that scales “are an efficient approach to solving the formula described above. They give you just about every combination of sounds that you will want to make, whether playing Bach, Brahms, Tchaikovsky, Stockhausen, jazz, or rock.” Mazzeo then outlines seven scale study books for the clarinet, providing a logical order in which to study them and his reasons for recommending them. He emphasizes the necessity of cleanliness of finger motions without involving movement of the rest of the hand, the importance of making the upward finger motion as controlled as the downward motion, and the careful analysis of particular fingering problems.

In *The Art of Oboe Playing* by Sprenkle and Ledet, the authors stress the use of gentle finger pressure and proper holding of the instrument to eliminate tension in the fingers, combined with rhythmically precise movements. They clarify the cause of the difficulty of lifting one finger while another finger is going down as follows: “At first this might seem like a simple seesaw action, but further examination shows a more complicated effect. Whereas the lifting of a pad produces an immediate effect because the change of notes is made as soon as the finger starts to move, the lowering of a pad has a delayed effect because the change does not come until the pad closes the hole at the end of the finger movement.”

---


faster then descending ones. The authors recommend practicing trills in triplet motion because in this way the two notes will be stressed in alternation.

Oboist Evelyn Rothwell, in *Oboe Technique*, advises the following: "The best way to acquire finger control is to practice scales and exercises, starting with those in the easier keys. Start very slowly and increase the speed only gradually, always playing rhythmically and evenly...Remember that however slowly you are moving from note to note, your fingers must react quickly; but the more slowly you practice, the more quickly will your fingers learn control." In a later chapter on practice strategy, Rothwell states that scales "are the backbone of your technique and therefore of your practice. Nothing will improve your playing as much in a short time as regular work with scales."

In *Bassoon Technique*, a book from the same series as the above, author Archie Camden states that "the basis on which an adequate finger technique is built is the regular practice of scales and arpeggios. This is the only way to produce fluent and even passage playing..." Camden advises playing all major and minor scales by memory, mastering one before starting to work on the next one. He includes a page in C major which should serve as a model for practicing in all keys. It provides the scale itself, arpeggios of C major and of the dominant seventh, the scale in thirds, and

---

48 Rothwell 63.
variations utilizing notes interspersed between scale notes. He also suggests working on chromatic scales and whole tone scales. An additional piece of advice from Camden on scale practice is that "you must remember to relax all the time, and to guard against lifting the fingers too high, for this is a waste of time and leads to inaccuracy." 

Scale Studies for the Bassoon

Among the best-known scale studies published for the bassoon are the Oubradous, *Enseignement Complet du Basson*, the Almenraeder "Scale Exercises in all keys" which is included in the Weissenborn, *Method for Bassoon*, the Parés *Scales and Daily Exercises*, the Satzenhofer, *Praktische Fagott-Schule*, the Giampieri, *Metodo Progressivo per Fagotto*, and the Milde, *Twenty-five Studies in Scales and Chords*, op. 24. In the well-known questionnaire by Dr. Ronald Klimko, *Bassoon Performance Practices and Teaching in the United States and Canada*, in which 106 bassoonists were surveyed on a wide range of performance and teaching topics, one of the questions was what technical study materials are used with undergraduate students and graduate students. Sixty-nine listed the Milde Op. 24, twenty-two listed the Piard *Scales and Arpeggio Studies*, books 1, 2, and 3, as well as six who listed it at the graduate level, twelve listed Kovar 24 *Daily Exercises*, eleven listed the Giampieri

---

50 Camden 18.

51 Camden 16.
16 Daily Studies, and forty-seven listed the Weissenborn Method for Bassoon, in which the Almenrader studies appear, although no one specifically mentioned them.\textsuperscript{52}

Of these, the Oubradous (in the first two of its three volumes) is useful in that it provides two pages for each major scale, followed by two pages for its relative minor scale, on which are the scale in triplets and sixteenths, the scale in thirds and then in fourths, the arpeggios of the tonic and the dominant seventh, and an exercise in the key. It proceeds through the keys by adding one sharp, then one flat, then two sharps, then two flats, etc. There are fifteen variations of articulation and rhythm to be applied to practice of the material.\textsuperscript{53}

The Almenraeder scale exercises are simply one octave scales in eighth notes beginning on each note of the scale, and descending in reverse order. They are the same material for each key, proceeding in the order of major keys (each followed by its relative minor) starting with C major and then adding one sharp at a time, through B major, followed by major keys starting with one flat, through $G^b$ major.\textsuperscript{54}

The Parés book provides scale exercises in major keys in the order of C major, followed by flat keys through $G^b$ major, then only the first two sharp keys. Material is in sixteenth notes with various articulations. Following is a very short section of minor

\textsuperscript{52} Ronald J. Klimko, \textit{Bassoon Performance Practices and Teaching in the United States and Canada} (Moscow, Idaho: School of Music Publications, 1974) 15.


\textsuperscript{54} Carl Almenraeder, revised P. X. Laube, \textit{Scale Exercises in all keys}. 
scales, a section on chromatic scales, then diatonic triplets, chromatic triplets, and arpeggios, although this material is presented in only a few keys.55

In the Satzenhofer Praktische Fagott-Schule is a section entitled “Exercises in all keys” in which each major scale and its relative minor is presented in whole notes, then in sixteenth notes, followed by its arpeggio in sixteenth notes and an etude. Keys are presented in the order of C major, a minor, then one flat, then one sharp, through G\textsuperscript{b} major and F\textsuperscript{#} major. The material for each key is one page or less.56

In the Metodo Progressivo by Giampieri are preparatory exercises for the scales, consisting of the first five notes up and down the scale of each major and minor key, presented in chromatic order, followed by only two pages of the scales, in eighth notes through five flats and six sharps, with each major key followed by its relative minor. Next is a short section of arpeggios in eighth notes and etudes in each key through four sharps and four flats. In the appendices are chromatic scales, whole tone scales, arpeggios, and scales in thirds, all presented in sixteenth notes. Unusual and of special value is the page on whole tone scales which presents the whole tone scales going up and down two octaves and starting on each chromatic note.57


56 Julius Satzenhofer, Praktische Fagott-Schule (Frankfurt-Main: Zimmermann copyright 1900).

57 Almiro Giampieri, Metodo Progressivo per Fagotto (Milan: Ricordi, 1949).
The Milde studies are well-known to bassoonists everywhere. They consist of two one-page etudes in each major key through five flats and six sharps, ending with a chromatic study. These valuable studies include scale passages as well as arpeggio passages in rhythm patterns of sixteenth notes, primarily.¹⁸

Some material for the bassoon is not based on scales, but instead presents groups of particularly difficult intervals. Volume three of the Oubradous Enseignement Complet du Basson contains groups of four, eight, and twelve sixteenth notes in difficult combinations.

Selected Practice Strategies

In addition to daily scale practice there are a number of other strategies which may help a player improve finger coordination. These strategies come from such diverse fields as brain research, sports training techniques, and psychology. They may be conveniently divided into two areas: physical strategies and mental strategies. Physical strategies are those in which various methods of drilling are used, such as isolating small passages or working in rhythms other than that which is printed in the music. Mental strategies are those in which new ways of thinking about the movement are used to improve it.

Physical Strategies

The following physical strategies were obtained from books and articles on the playing of the various woodwind instruments. Due to the similarities of finger technique among the woodwind instruments, many strategies transfer well to the bassoon. Although string and piano technique resources could provide useful suggestions to the bassoonist, a survey of those materials would be beyond the scope of this project.

One physical strategy which is widely used is that of practicing a passage in various rhythms. For example, a passage of fast sixteenth notes may be practiced in dotted rhythms, both “long-short” and “short-long.” This seems to work because it allows the player to work on the quick changes for every other note at a time, rather than on the quick changes for each note. To maintain the proper timing, however, it is of critical importance to practice both types of dotted rhythms. In volumes one and two of the Oubradous *Enseignement Complet du Basson* is a particularly complete list of other possible rhythms in which to practice.

A physical strategy suggested by clarinetist J. McCardell Hinson involves working with the hands on a table and raising and lowering the fingers, one at a time, while maintaining complete relaxation, and moving only from the knuckle. A second exercise, done in the same way, alternates between two fingers to develop better finger independence, while a final exercise is done while holding the clarinet but not playing. This exercise requires raising and lowering the same finger of each hand to a
metronome beat. Another suggestion is to practice each hand separately, without blowing, before combining the movements of the two hands.

**Finger Height and Pressure.** Another widely recognized strategy is that of minimizing the height that the fingers are lifted away from the keys or tone holes, and maintaining this height for all of the fingers. Many authors stress the importance of lifting all of the fingers the same height to insure more accurate coordination between notes involving the lifting of two or more fingers. Flutist, Victoria Grenier states that many players who raise their fingers too high “clomp down on the flute with the force of Hercules. This practice inhibits finger facility, creates accents where there should be none, and makes too much noise. It’s also important for players to hold the fingers the same distance from the keys so the tone holes can be depressed simultaneously.

Fingers held at different heights result in unintentional fingerings and wrong notes.”

Clarinetist, Arthur Henry Christmann notes the tendency of a player when playing loudly, to “press hard with his fingers, lift them high, perhaps slap them down...” Christmann states that as a young player he believed that fingers “should act with a certain amount of force and precision and that the ‘click’ between tones was desirable,” but that after two lessons with flutist, Georges Barrère, who stressed “low, light, but precise finger action, avoiding all tension and keeping the fingers as near the

---


holes as possible, but still playing with rhythmic exactness and regularity," he changed his finger motions and reported that his technique improved immeasurably.\textsuperscript{61}

On the bassoon, the player has the disadvantage of being able to see only the left thumb while playing, and this only with great difficulty. It may be beneficial, therefore, to practice in front of a full-length mirror in order to observe the finger heights. The player may observe a finger slightly missing its destined hole or moving later than the other fingers involved in the change to the next note. The player is also able to observe the height that the fingers are being lifted from the keys.

Another way for the player to observe the finger movement would be to use a video camera focused on the fingers of one hand with live playback on a television screen. Unfortunately, the camera can not be set up so that both sides of the bassoon are visible on the screen at the same time. The player would be able to see a close-up of only one of the thumbs or the fingers of one hand. This is a drawback because many of the bassoonist's coordination problems are between the thumb and the fingers or between the fingers of two different hands. The private teacher can also be helpful to the bassoon student in watching and describing any fingering problems.

Another possibility is that of having another person hold a hand or a ruler about an inch above the player's fingers as they rest on the bassoon. The player can then be aware of the height the fingers are lifting by whether or not they touch the

other person's hand, or the ruler. As in the transmission of electrical current, the shorter the distance, the faster the goal may be reached.

_Supporting the bassoon._ Closely related to the maintenance of light finger pressure is the method used by the player to support and balance the instrument. In the case of the oboe, the flute, and the clarinet, the player must take the weight of the instrument on the right thumb, which often leads to tension in the right hand. Due to the weight of the saxophone, a neck strap is used to support some of the weight of the instrument in addition to the right thumb. Because bassoonists are rarely required to play in the standing position, the focus of this section will be on balance and support of the instrument while seated.

The bassoonist's problem is somewhat different from the other woodwinds in that the instrument's weight is mostly on the seat strap, but the player must balance the bassoon with the first joint of the left hand's index finger and the right outer thigh. When the bassoon is held at an angle that leans the bell of the bassoon too far forward, an inordinate amount of the weight falls on the left hand, inhibiting finger movement. Proper bassoon balance also depends on having an adequate chair. A good chair should not lean the player too far forward or backward, and should have a seat depth sufficient to allow the seat strap to be placed on the chair far enough forward so that the boot joint is properly resting on the forward part of the player's right outer thigh. Only with the boot towards the front of the chair can the bassoon be held vertically enough to keep the weight of the instrument off of the player's left fingers. For better
balance, some players use a guitarist's footrest under the right foot to raise the right thigh.

Some bassoonists use the neck strap rather than the seat strap to take the weight of the bassoon (especially if it is necessary to stand while playing). As an option, the neck strap may be attached to a special device mounted onto the bassoon, called a balance hanger, which serves to alter the balance point of the instrument to a more comfortable playing position. In order to maintain proper balance of the bassoon in the absence of support from the player's thigh, a hand rest is often used under the right thumb. Some bassoonists use the hand rest when seated, as well, in the belief that it positions the fingers and thumb advantageously. The important point is that the player avoid supporting the instrument in any way with the fingers, themselves, for optimum freedom of finger movement.

While recovering from his hand surgery, Dr. William Dietz, associate professor of bassoon at the University of Arizona, invented a different balance system which completely frees the fingers from holding the bassoon. It consists of a belt to be worn around the player's waist with a hook attached to it onto which the neck strap ring (located on the back of the bassoon's boot joint) is hung. The seat strap is still used to support the main weight of the bassoon. Disadvantages are that the use of the belt can be a slight impediment to breathing, and that it can be tiring to the back.\footnote{William Dietz, "Supporting the Bassoon," \textit{The Instrumentalist}, 44.10 (1990): 52.}
Another practical suggestion for improving finger coordination is to find a playing position in which straight wrists may be maintained. Not only is there a physiological basis for this strategy (as is described on page 36), the practical advantage is easily demonstrated as follows. Holding the elbow on a table with wrist straight and the fingers pointing to the ceiling, wiggle the fingers. Compare the ease of movement to wiggling the fingers in the same position, but with the wrist bent at a ninety-degree angle. The difference should be readily apparent. In bassoon playing, the left wrist may be straightened by readjusting the horizontal orientation of the instrument. The right wrist may be straightened by holding the right elbow further from the body. These adjustments to the playing position may require the bocal to be turned to an angle different than that to which the player has been accustomed.

**Interpreting aural indications of poor coordination.** Perhaps the most obvious sign of faulty finger coordination is the aural effect. This is, of course, the most important reason for trying to improve one's finger coordination. On the bassoon, aural indications may include distortions at the beginning of a new note or extra notes heard when moving more than a step, or whenever more than one finger must be moved in a given fingering change. Unfortunately, many young bassoonists become so accustomed to the distortions in sound that arise from faulty finger technique that they cease to notice them and hence, do nothing to correct them. Judicious use of the tape recorder can be quite a revelation. An example of moving more than one finger for a
change of only a half-step is the move from B♭ to B, in which both the right middle finger and the right thumb must be lifted at the same time. The reason for extra notes being heard is that the fingers may not all be lifted at the same instant. If the thumb rises from the B♭ key before the middle finger rises, an A is briefly heard, while if the middle finger rises from the tone hole before the thumb rises, an out-of-tune B is heard.

Once this type of problem is understood, another highly useful strategy, undoubtedly used by many, may be employed. It is concisely stated by Tom Hinds in Klimko’s survey. He says that “for smoothness in technique (‘blips’ between notes) I figure which finger(s) are moving too slow, 1) play the first note 2) move the slow finger(s) 3) move the others, then diminish time between 2) and 3) until it’s smooth.”

Other aural signs of faulty coordination on the bassoon are notes that do not sound at the expected pitch, but instead sound as growls or squeaks. These problems are often due to an incorrect use of the half hole or the failure to flick when needed (or at the proper instant) for a difficult slur. Aural signs are important in that they tell the player the precise instant at which faulty coordination has occurred. The main problem is that they occur so quickly that it is often extremely difficult to tell what has gone wrong. Weisberg states that “our ear must be trained to analyze very quickly, because the notes are being played so fast. The ear must hear only the problem note or notes

---

63 Hinds in Klimko 59.
and not the one before or the one after," and that "we must find the exact point where the difficulty starts."^{64}

Mental Strategies

Mental strategies for improving finger coordination come from the diverse fields of "Inner Game" theory, sports psychology, and schools of movement training such as the Alexander Technique. These areas have much to offer the woodwind player in obtaining greater muscle relaxation, and therefore, improved freedom of movement.

**Inner Game Theory.** Inner Game theory is a relatively recent innovation in the field. It originated with former tennis pro W. Timothy Gallwey, in his 1975 book, *The Inner Game of Tennis* in which he described his experiences in both tennis tournament playing and in teaching tennis.^{65} He developed methods for the elimination of the distraction of negative "self-talk" and for the improvement of concentration on the task by refocusing one's concentration on such aspects as the rotating seams of the tennis ball. From his book have sprung several others on various sports, as well as Barry Green's, *The Inner Game of Music*, in 1986.^{66} Green is a professional orchestral

---

64 Weisberg 77.


bassist who collaborated with Gallwey in transferring his original principles from tennis to music.

Not only can the inner game techniques help performers overcome stage fright by monitoring the state of their bodies, they can also increase one’s concentration in the practice session. A representative technique is to simply become more aware of one’s activities by listening to the sounds produced and by monitoring for muscle tension, all of this while avoiding negative judgements about one’s playing, such as the thought “That was terrible.” Judgements lead to tension as one tries too hard to make corrections. Some of the factors that Green suggests musicians become more aware of are the printed music (by looking closely at all the dynamic markings and phrasing), the sound (without any self-talk), the emotional content of the music, and the way the body feels as it plays. For each of these areas, exercises are provided for the musician.67 Another interesting technique is that of giving oneself permission to fail, which surprisingly often leads to a more successful performance of a difficult passage, most likely because the fear of failure has been overcome.68 Green also provides a script to be read into a tape recorder and listened to while in a physically relaxed state, in which the performer is to visualize a successful public performance.69

67 Green 39-42.
68 Green 33.
Green offers specific help for the various families of instruments. For finger coordination difficulties in the woodwinds he suggests that if a note doesn’t speak, the player must notice which fingers are not completely covering the keys, and that the player should notice the rhythmic clicking of the keys and whether they are precisely in tempo.70

Mental Imagery. One of the more effective techniques in sports psychology that can be easily transferred to musicians is the use of mental imagery to improve movement. Flutist, Betty Bang Mather describes a practice technique in which the player first fingers through a difficult passage without making sound, repeating it several times to get the feeling of it well in the mind. Then the player should just imagine the movement, noticing that the sensations are nearly the same as when it was actually produced. After several repetitions, the player should then perform the difficult passage and most likely will experience greater ease.71

Another aspect of sports psychology concerns the training schedule. Stephen A. Mitchell, a medical doctor and flutist has applied several principles from sports medicine to music. He recommends making training specific to the skill you are trying to learn, scheduling intensive practice days in which you push yourself to the limit but easy practice days before a taxing performance. He also recommends staying in shape

70 Green 138-139

on your instrument, and avoiding pushing yourself to the point of muscular pain and emotional burnout.\textsuperscript{72}

\textbf{Alexander Technique.} Alexander Technique originated with the turn-of-the-century Australian actor, F. M. Alexander. When doctors could not determine the cause of his serious throat irritation and hoarseness, Alexander began a process of self-observation from which he eventually was able to determine that by realigning his head, neck, and torso his problems abated. Three main principles of the technique are that the neck must be free and be aligned with the spine, the head should be carried forward and up, and the torso should be held lengthened.\textsuperscript{73} Misuse of the body through bad habits is identified and redirected, resulting in an economy of effort in movements and proper redistribution of tension. A recent survey of professional orchestral musicians showed widespread use of the technique.\textsuperscript{74}

Bassoonist, Glyn Williams, of London, England, is a teacher of Alexander Technique. He explains that although musicians spend years developing flexibility in their hands, many ignore the rest of the body. This often results in discomfort or pain, possibly even injury, and at the very least, inefficient playing. The Alexander teacher physically manipulates the student and teaches him or her how to continue the process


of relieving muscular tension. There are many case studies of musicians whose progress through Alexander Technique has been published in journal articles.

**Feldenkrais Method.** Moshe Feldenkrais was an Israeli physicist, engineer, mathematician and martial artist who was also educated in neural sciences. He taught himself how to recognize the quality of movements and how to break poor habits and replace them with more efficient ones. Although the method has a number of similarities to the Alexander Technique, it is based on scientific principles such as the laws of gravity and motion. Feldenkrais discarded any manipulation that could not be proven to solve a problem. Sessions are broken down into various types of manipulations to help the client to use the body in more efficient ways. There is an emphasis on learning each new skill based upon mastery of prior skills. As is the case with Alexander Technique, many case studies have been published about musicians who have benefited from the Feldenkrais Method.

There are many other general techniques that can help musicians to release muscle tension and gain efficiency in their movements, thereby improving their coordination. A few examples would be Tai Chi, various forms of meditation disciplines, and yoga.

---


76 Mather 27.

VII. BASSOONIST'S COORDINATION MEASUREMENT SYSTEM

The purpose of the development of the Bassoonist's Coordination Measurement System, or BCMS, was to allow the player to clearly determine which fingers are responsible for the errors in passages of poor coordination. The system provided a means for showing immediate visual feedback on the computer screen as notes were played. This feedback appeared in the form of a "1" or a "0" for each finger, and also showed the letter name of the note if it was a finger combination of an actual note. If the finger combination was not an actual note, an asterisk was shown. The system provided the capability of storing data on disk and printing it for later for analysis.

Design and Development

At the time of the original conception of the project, the author was not yet familiar with the work by Gary L. Callahan, whose research is described in chapter three. The design of the BCMS evolved through several different stages, beginning with the idea of the player wearing gloves which would have contacts attached to the tip of each finger. When the finger was placed on a hole or a key, the contact would be established and monitored by the computer. When the finger was lifted, the contact would be discontinued. This design was eliminated when the author realized the difficulty of playing the bassoon with gloves on. Another problem with this design was
that in bassoon playing, the fingers often slide from key to key, which would quickly damage or move the contacts out of position.

Robert E. McNabb, a retired electrical engineer and the father of the author, developed a new design for the BCMS, in which the motion of the opening and closing keys would operate wire levers, which in turn would press or release small toggle switches. In the case of fingers covering tone holes directly, the levers were to be placed close to the tone holes, so that the pressure by the fingers would directly operate the levers, rather than the motion of the keys operating them. The switch positions would be monitored by the computer for any change in their positions, sampling each of the three ports of seven switches every ten-thousandth of a second. Whenever a change was detected, a new line would appear on the computer screen, showing the positions of all the switches and the time (to the ten-thousandth of a second) since the last change in a switch position had occurred.

The computer program was originally designed to display only the elapsed time and the line of ones and zeroes, but this was tedious to interpret. Therefore, a new section was added to the computer program, in which the particular combination of switch settings was filtered through a table to determine and display the letter name of the note being played. Any time the switch combination was not an actual note, an asterisk would be displayed. This was a convenient way to see the precise instant at which poor coordination occurred. Unfortunately, the process of filtering a switch combination through the table took a small amount of time that varied depending on
the number of lines in the table through which the combination had to travel before finding a match to a note name. For this reason it could not be done in real time and continue to display accurate elapsed timings since the last switch position change.

Another option was then added to the computer program when this was discovered, in which the player could stop playing at any point and display the last 20 lines of data on the screen. The player still had the option to display the note names while playing, but timings would not be accurate.

**Components**

The BCMS consisted of the following components.

1) Movement registration switches, the type of miniature switches typical of those mounted under keyboard push buttons

2) Wooden blocks (felt-backed) onto which movement registration switches and levers to activate them were mounted

3) Elastic strips with Velcro tabs sewn on, to hold the device in place on the bassoon

4) Gateway 2000 computer model 4DX2-66 (IBM compatible), with eight megabytes of Random Access Memory (RAM) and 540 megabytes of hard disk memory, with an operating speed that enabled sampling of each switch position 10,000 times per second.

5) Epson LQ-570 printer
6) Parallel Digital Interface Board, a Keithley MetraByte Corporation Model PIO-12, with three input/output ports, each capable of accommodating up to 8 inputs or outputs

7) Bassoon Interface Circuit Board with wires connecting to each movement registration switch, and interfacing with the Parallel Digital Interface Board, as designed and built by Robert E. McNabb

8) Program written in QBASIC (version for Microsoft MS-DOS 6.2) by Robert E. McNabb

The BCMS was designed to input 23 individual switches, or eight per input port, with one not used. The bassoon actually has more keys than this, necessitating that choices had to be made that would leave out a few of the less frequently used keys, such as trill keys. The keys that were not to be monitored were the high d" key, the left hand trill keys for f-g and f-f#, the c# trill key and the B♭ trill key. Appendix A contains a chart of the input assignments for each key. The low register keys were intended to be monitored, but in actual use of the BCMS, it was found that the BB♭, BB, and C keys could not readily be adjusted so that they would both operate the levers and close the pads properly; therefore this part of the device was not used.

A major drawback in using the BCMS was that firm finger pressure was needed to keep the levers down while the fingers were on a tone hole. Although the original plan for the device was to use it for daily practice on a group of targeted, difficult
intervals and the piece chosen for the project, Malcolm Arnold’s *Fantasy for Bassoon*, *Op. 86*, the author quickly realized that to do so would be detrimental, in that it would necessitate the habit of overly firm finger pressure. One of the traditional approaches to improving finger coordination that appears frequently in woodwind-related books and articles is to minimize finger pressure. For this reason, the author chose to use the BCMS primarily as a diagnostic tool at the beginning of the project.

**Analysis of Data**

Ten difficult intervals were performed using the device. Each was performed between five and ten times and the results were printed for analysis. The intervals chosen represented a full range of difficulty, from the movement of two fingers up at the same time (B-d) through a combination involving a complete reversal of the two fingers pressed down on the right hand to the other two and thumb, with a movement of the left hand thumb from the pressing the whisper key down to pressing the next two higher keys down, and closing the half hole (g'-a').

Following is a sample of the raw data printout (the same information that appeared on the computer screen) for the descending interval, d♯-c♯, with an explanation of how it was interpreted, then how the line would appear in the data tables. Note that the fingers are numbered with the thumb as “1” to the little finger as “5.” The designation “L1” would indicate a movement by the left thumb. The arrow
tells the direction of the finger movement, either up or down. When the finger has
more than one key it could operate, the name of a key is given following the arrow.

<table>
<thead>
<tr>
<th>LINE NO.</th>
<th>TIME</th>
<th>PORT A</th>
<th>PORT B</th>
<th>PORT C</th>
<th>PITCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>116</td>
<td>0.019</td>
<td>L1↓D</td>
<td>L1↓c#</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.019</td>
<td>L1↓c#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sample Table line, d♯↓c♯
The sample data shows the descending interval, d♯-c♯. The d♯ was held for
0.921 seconds before the low D key was closed by the left thumb, as shown on line
number 117, port A4. This position was held for 0.019 seconds before the c♯ key was
closed by the left thumb, in an upward rolling motion, as shown on line number 118,
port A2. At the same time (indicated by the time 0.000) on line number 119, the d tone
hole was closed by the left middle finger, port B2, and the E♭ key was released by the left little finger, port B0, producing the note, c♯. The total time for the transition once the d♯ was sounding was 0.019 seconds. This is nearly two one-hundredths of a second in faulty coordination between the time the low D key was pressed and the rest of the movement was completed.

Note that for the tables, all of the transition times were added together for a total time. In some of the tables there were less than five valid trials due to occasional problems with movement of the switch mounting blocks, but in other cases there were several more valid trials. In the latter case, only the first five trials were included on the table; however the conclusions drawn from analysis of the data take into consideration all valid trials.

Some of the tendencies discovered in the data analysis were:

1. In the descending interval d-B, in which the left ring finger and the right index finger must close together, the left hand ring finger was almost always late going down. This is not surprising because the ring finger is a much weaker finger than the index finger.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Total Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R2↑</td>
<td>L4↑</td>
<td>0.021</td>
<td>Worst</td>
</tr>
<tr>
<td>2</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.004</td>
<td>Best</td>
</tr>
<tr>
<td>4</td>
<td>R2↑</td>
<td>L4↑</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>R2↑</td>
<td>L4↑</td>
<td>0.010</td>
<td></td>
</tr>
</tbody>
</table>
Table 1B, d↓B

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Total Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R2↓</td>
<td>L4↓</td>
<td>0.019</td>
<td>Worst</td>
</tr>
<tr>
<td>2</td>
<td>R2↓</td>
<td>L4↓</td>
<td>0.004</td>
<td>Best</td>
</tr>
<tr>
<td>3</td>
<td>R2↓</td>
<td>L4↓</td>
<td>0.014</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>R2↓</td>
<td>L4↓</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>R2↓</td>
<td>L4↓</td>
<td>0.014</td>
<td></td>
</tr>
</tbody>
</table>

2. In the ascending interval f-g, in which all fingers must go down together (also known by woodwind players as "going over the break"), the middle fingers of both hands were often the last to go down. This may have been caused by the tendency of these fingers to straighten out when not covering their tone holes. In the descending interval g-f (the same two notes), the left ring finger was often the last finger to go up.

Table 2A, f↑g

<table>
<thead>
<tr>
<th>T</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L4↓</td>
<td>R4↓</td>
<td>R3↓</td>
<td>L5↓</td>
<td>L2↓</td>
<td>R2↓</td>
<td>L3↓</td>
<td>0.025</td>
<td>Best</td>
</tr>
<tr>
<td>2</td>
<td>L4↓</td>
<td>L5↓</td>
<td>R4↓</td>
<td>R2↓</td>
<td>L2↓</td>
<td>R3↓</td>
<td>L3↓</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L4↓</td>
<td>L5↓</td>
<td>R4↓</td>
<td>L2↓</td>
<td>R2↓</td>
<td>L3↓</td>
<td>L3↓</td>
<td>0.034</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L4↓</td>
<td>R2↓</td>
<td>L2↓</td>
<td>R4↓</td>
<td>L5↓</td>
<td>L3↓</td>
<td>R3↓</td>
<td>0.058</td>
<td>Worst</td>
</tr>
<tr>
<td>5</td>
<td>L4↓</td>
<td>R2↓</td>
<td>R4↓</td>
<td>L2↓</td>
<td>L5↓</td>
<td>R3↓</td>
<td>L3↓</td>
<td>0.026</td>
<td></td>
</tr>
</tbody>
</table>

Table 2B, g↓f

<table>
<thead>
<tr>
<th>T</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L2↑</td>
<td>L5↑</td>
<td>R4↑</td>
<td>L3↑</td>
<td>R2↑</td>
<td>R3↑</td>
<td>L4↑</td>
<td>0.087</td>
<td>Worst</td>
</tr>
<tr>
<td>2</td>
<td>L2↑</td>
<td>L3↑</td>
<td>R4↑</td>
<td>R2↑</td>
<td>L5↑</td>
<td>R3↑</td>
<td>L4↑</td>
<td>0.042</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L5↑</td>
<td>R4↑</td>
<td>L3↑</td>
<td>R3↑</td>
<td>R2↑</td>
<td>L2↑</td>
<td>L4↑</td>
<td>0.037</td>
<td>Best</td>
</tr>
<tr>
<td>4</td>
<td>R2↑</td>
<td>L2↑</td>
<td>L5↑</td>
<td>R4↑</td>
<td>L3↑</td>
<td>R3↑</td>
<td>L4↑</td>
<td>0.043</td>
<td></td>
</tr>
</tbody>
</table>
3. In a similar set of intervals, \( f-f^\# \), which also goes over the break but includes the right thumb going down with the other fingers, the left hand middle finger was often near the last to go down. This could be due to the fact that this note requires the largest half-hole on the bassoon executed by the finger above it, the left index finger, leaving the middle finger slightly displaced.

<table>
<thead>
<tr>
<th></th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Seq. 8</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L4↓</td>
<td>R2↓</td>
<td>R5↓F</td>
<td>R5↓F#</td>
<td>L2↓</td>
<td>L3↓</td>
<td>R3↓</td>
<td>R4↓</td>
<td>0.025</td>
<td>Best</td>
</tr>
<tr>
<td>2</td>
<td>R2↓</td>
<td>L4↓</td>
<td>R5↓F</td>
<td>R5↓F#</td>
<td>L2↓</td>
<td>L3↓</td>
<td>R4↓</td>
<td>R3↓</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L4↓</td>
<td>R2↓</td>
<td>L2↓</td>
<td>R5↓F</td>
<td>R5↓F#</td>
<td>L3↓</td>
<td>R4↓</td>
<td>R3↓</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>R2↓</td>
<td>L4↓</td>
<td>R5↓F#</td>
<td>R5↓F</td>
<td>R4↓</td>
<td>L2↓</td>
<td>R3↓</td>
<td>L3↓</td>
<td>0.052</td>
<td>Worst</td>
</tr>
</tbody>
</table>

Table 3A, \( f\uparrow f^\# \)

3. In a similar set of intervals, \( f-f^\# \), which also goes over the break but includes the right thumb going down with the other fingers, the left hand middle finger was often near the last to go down. This could be due to the fact that this note requires the largest half-hole on the bassoon executed by the finger above it, the left index finger, leaving the middle finger slightly displaced.

<table>
<thead>
<tr>
<th></th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Seq. 8</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L4↑</td>
<td>R3↑</td>
<td>R4↑</td>
<td>R5↑F</td>
<td>L3↑</td>
<td>R4↑</td>
<td>R4↑</td>
<td>L2↑</td>
<td>0.047</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R4↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>L5↑F</td>
<td>R5↑F#</td>
<td>L2↑</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>R4↑</td>
<td>L2↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.063</td>
<td>Worst</td>
</tr>
<tr>
<td>4</td>
<td>R3↑</td>
<td>R4↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>R2↑</td>
<td>L2↑</td>
<td>L4↑</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>R4↑</td>
<td>L2↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>R2↑</td>
<td>L4↑</td>
<td>0.040</td>
<td>Best</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Seq. 8</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L4↑</td>
<td>R3↑</td>
<td>R4↑</td>
<td>R5↑F</td>
<td>L3↑</td>
<td>R4↑</td>
<td>R4↑</td>
<td>L2↑</td>
<td>0.047</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R4↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>L5↑F</td>
<td>R5↑F#</td>
<td>L2↑</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>R4↑</td>
<td>L2↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>L4↑</td>
<td>R2↑</td>
<td>0.063</td>
<td>Worst</td>
</tr>
<tr>
<td>4</td>
<td>R3↑</td>
<td>R4↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>R2↑</td>
<td>L2↑</td>
<td>L4↑</td>
<td>0.041</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>R4↑</td>
<td>L2↑</td>
<td>R3↑</td>
<td>L3↑</td>
<td>R5↑F</td>
<td>R5↑F#</td>
<td>R2↑</td>
<td>L4↑</td>
<td>0.040</td>
<td>Best</td>
</tr>
</tbody>
</table>

4. In the descending interval B\(^b\)-A\(^b\), involving the right hand thumb rising, and the right hand middle finger and little finger pressing, the little finger was always the last to go down. A likely explanation is that the little finger was being held too high above its key.
Table 4. $B^b \downarrow A^b$

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R1 \uparrow B^b$</td>
<td>$R4 \downarrow$</td>
<td>$R5 \downarrow A^b$</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$R1 \uparrow B^b$</td>
<td>$R4 \downarrow$</td>
<td>$R5 \downarrow A^b$</td>
<td>0.001</td>
<td>Best (tie)</td>
</tr>
<tr>
<td>3</td>
<td>$R1 \uparrow B^b$</td>
<td>$R4 \downarrow$</td>
<td>$R5 \downarrow A^b$</td>
<td>0.014</td>
<td>Worst</td>
</tr>
<tr>
<td>4</td>
<td>$R4 \downarrow$</td>
<td>$R1 \uparrow B^b$</td>
<td>$R5 \downarrow A^b$</td>
<td>0.010</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$R4 \downarrow$</td>
<td>$R1 \uparrow B^b$</td>
<td>$R5 \downarrow A^b$</td>
<td>0.001</td>
<td>Best (tie)</td>
</tr>
</tbody>
</table>

5. In the descending interval $B^b$-alternate $G^b$, the sequence of events varied, but the right ring finger was generally the first down.

Table 5. $B^b \downarrow$ Alternate $G^b$

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Total Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$R4 \downarrow$</td>
<td>$R5 \downarrow F^#$</td>
<td>$R1 \uparrow B^b$</td>
<td>$R5 \downarrow F$</td>
<td>0.039</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$R4 \downarrow$</td>
<td>$R1 \uparrow B^b$</td>
<td>$R5 \downarrow F$</td>
<td>$R5 \downarrow F^#$</td>
<td>0.017</td>
<td></td>
</tr>
</tbody>
</table>

6. In the descending interval $d-c^#$, the $c^#$ key was often the last to go down. This key is pressed by the left thumb in a rolling motion while keeping the thumb on the whisper key. In the ascending interval of the same two notes, the left ring finger was often the last to be lifted. This could be due to exerting too great a pressure. It is difficult to maintain light finger pressure with this finger when the left thumb is pressing directly opposite.

Table 6A. $c^# \uparrow d$

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$L1 \uparrow c^#$</td>
<td>$L4 \uparrow$</td>
<td>$L1 \uparrow D$</td>
<td>0.081</td>
<td>Worst</td>
</tr>
<tr>
<td>2</td>
<td>$L1 \uparrow c^#$</td>
<td>$L1 \uparrow D$</td>
<td>$L4 \uparrow$</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$L1 \uparrow c^#$</td>
<td>$L4 \uparrow$</td>
<td>$L1 \uparrow D$</td>
<td>0.052</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$L1 \uparrow c^#$</td>
<td>$L1 \uparrow D$</td>
<td>$L4 \uparrow$</td>
<td>0.058</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$L1 \uparrow c^#$</td>
<td>$L1 \uparrow D$</td>
<td>$L4 \uparrow$</td>
<td>0.028</td>
<td>Best</td>
</tr>
</tbody>
</table>
In the difficult interval, c\#-d\#, the type of error varied between the c\# key release by the left thumb and the left middle finger lifting, but in the descending interval of the same two notes, the c\# key was generally late going down, as was the case in the previous interval, d-c\#.

Table 6B, d\downarrow c\#

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1\downarrow D</td>
<td>L4\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.087</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>L1\downarrow D</td>
<td>L4\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.118</td>
<td>Worst</td>
</tr>
<tr>
<td>3</td>
<td>L1\downarrow D</td>
<td>L4\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.051</td>
<td>Best</td>
</tr>
<tr>
<td>4</td>
<td>L1\downarrow D</td>
<td>L4\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.090</td>
<td></td>
</tr>
</tbody>
</table>

Table 7A, c\#\uparrow d\#

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1\uparrow c#</td>
<td>L1\uparrow D</td>
<td>L3\uparrow</td>
<td>L5\downarrow E#</td>
<td>0.041</td>
<td>Worst</td>
</tr>
<tr>
<td>2</td>
<td>L1\uparrow c#</td>
<td>L1\uparrow D</td>
<td>L3\uparrow</td>
<td>L5\downarrow E#</td>
<td>0.033</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L1\uparrow c#</td>
<td>L3\uparrow</td>
<td>L1\uparrow D</td>
<td>L5\downarrow E#</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L3\uparrow</td>
<td>L5\downarrow E#</td>
<td>L1\uparrow D</td>
<td>L5\uparrow c#</td>
<td>0.018</td>
<td>Best</td>
</tr>
<tr>
<td>5</td>
<td>L1\uparrow c#</td>
<td>L1\uparrow D</td>
<td>L3\uparrow</td>
<td>L5\downarrow E#</td>
<td>0.023</td>
<td></td>
</tr>
</tbody>
</table>

Table 7B, d\#\downarrow c\#

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1\downarrow D</td>
<td>L5\uparrow E#b</td>
<td>L3\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.081</td>
<td>Worst (tie)</td>
</tr>
<tr>
<td>2</td>
<td>L1\downarrow D</td>
<td>L3\downarrow</td>
<td>L5\uparrow E#b</td>
<td>L1\downarrow c#</td>
<td>0.079</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L1\downarrow D</td>
<td>L5\uparrow E#b</td>
<td>L3\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.081</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L1\downarrow D</td>
<td>L5\uparrow E#b</td>
<td>L3\downarrow</td>
<td>L1\downarrow c#</td>
<td>0.075</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>L1\downarrow D</td>
<td>L5\uparrow E#b</td>
<td>L1\downarrow c#</td>
<td>0.045</td>
<td>Best</td>
<td></td>
</tr>
</tbody>
</table>
8. In the ascending interval d–e\textsuperscript{b}, involving an exchange of the left hand middle and ring fingers, the middle finger was often the last to go up. In the descending interval of the same two notes, the ring finger was often the last to go up. Because the finger that had to be lifted was generally the late one, this seems to confirm that lifting motions are more difficult to coordinate than pressing ones.

Table 8A, d\uparrow e\textsuperscript{b}

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L5\downarrow E\textsuperscript{b}</td>
<td>L4\downarrow</td>
<td>L3\uparrow</td>
<td>0.008</td>
<td>Best (tie)</td>
</tr>
<tr>
<td>2</td>
<td>L5\downarrow E\textsuperscript{b}</td>
<td>L4\downarrow</td>
<td>L3\uparrow</td>
<td>0.020</td>
<td>Worst</td>
</tr>
<tr>
<td>3</td>
<td>L4\downarrow</td>
<td>L5\downarrow E\textsuperscript{b}</td>
<td>L3\uparrow</td>
<td>0.008</td>
<td>Best (tie)</td>
</tr>
<tr>
<td>4</td>
<td>L5\downarrow E\textsuperscript{b}</td>
<td>L3\uparrow</td>
<td>L4\downarrow</td>
<td>0.009</td>
<td></td>
</tr>
</tbody>
</table>

Table 8B, e\textsuperscript{b} \downarrow d

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Total time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L5\uparrow E\textsuperscript{b}</td>
<td>L3\downarrow</td>
<td>L4\uparrow</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>L5\uparrow E\textsuperscript{b}</td>
<td>L3\downarrow</td>
<td>L4\uparrow</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L5\uparrow E\textsuperscript{b}</td>
<td>L3\downarrow</td>
<td>L4\uparrow</td>
<td>0.036</td>
<td>Best</td>
</tr>
<tr>
<td>4</td>
<td>L5\uparrow E\textsuperscript{b}</td>
<td>L3\downarrow</td>
<td>L4\uparrow</td>
<td>0.052</td>
<td>Worst</td>
</tr>
<tr>
<td>5</td>
<td>L5\uparrow E\textsuperscript{b}</td>
<td>L3\downarrow</td>
<td>L4\uparrow</td>
<td>0.041</td>
<td></td>
</tr>
</tbody>
</table>

9. In the ascending interval c–a, involving the flicking technique by the left thumb, the thumb often reached the flick key late, after the right hand fingers had arrived in place for the higher note. This means that the flick was not doing the job it was intended to do, which is to help the a to speak in the higher octave. Note that for this table, the time the left thumb whisper key (wk) was open before the flick and the time the flick key (fl) was open were not added to the total time. It is normal to leave the whisper key early and to tap the flick key briefly, therefore this is not a sign of
faulty coordination. Because the flicking technique is primarily used for ascending intervals, the descending interval was not tested.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Total Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1↑wk</td>
<td>R3↓</td>
<td>R2↓</td>
<td>L1↓fl</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>L1↑wk</td>
<td>R3↓</td>
<td>R2↓</td>
<td>L1↓fl</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L1↑wk</td>
<td>R2↓</td>
<td>R3↓</td>
<td>L1↓fl</td>
<td>0.003</td>
<td>Best</td>
</tr>
<tr>
<td>4</td>
<td>L1↑wk</td>
<td>R2↓</td>
<td>R3↓</td>
<td>L1↓fl</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>L1↑wk</td>
<td>R2↓</td>
<td>L1↓fl</td>
<td>R3↓</td>
<td>0.060</td>
<td>Worst</td>
</tr>
</tbody>
</table>

10. The most difficult interval tested, high g'-high a', whose movement was described above, showed various types of faulty coordination, but the data did show that the left thumb was properly leaving the whisper key early in order to press the two keys higher. The descending interval of the same two notes showed again that the fingers on the right hand that had to be lifted were often the last part of the movement to be executed. Note that the left index finger (L2) opens and closes on the same trial in most cases. This is due to the finger shifting from an open half-hole to a completely closed hole.

<table>
<thead>
<tr>
<th>T</th>
<th>Seq. 1</th>
<th>Seq. 2</th>
<th>Seq. 3</th>
<th>Seq. 4</th>
<th>Seq. 5</th>
<th>Seq. 6</th>
<th>Seq. 7</th>
<th>Seq. 8</th>
<th>Seq. 9</th>
<th>Seq. 10</th>
<th>total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1↑wk</td>
<td>L2↑</td>
<td>R1↑B</td>
<td>R3↓</td>
<td>R5↑F</td>
<td>L1↓fl</td>
<td>L2↓</td>
<td>L1↓c</td>
<td>R3↓</td>
<td>R4↓</td>
<td>0.116</td>
</tr>
<tr>
<td>2</td>
<td>L1↑wk</td>
<td>L2↑</td>
<td>R2↑</td>
<td>R4↓</td>
<td>R5↑F</td>
<td>L1↓fl</td>
<td>L1↓c</td>
<td>R3↓</td>
<td>R4↓</td>
<td>L2↓</td>
<td>0.230</td>
</tr>
<tr>
<td>3</td>
<td>R2↑</td>
<td>L1↑wk</td>
<td>L2↑</td>
<td>R4↓</td>
<td>R5↑F</td>
<td>L1↓fl</td>
<td>L1↓c</td>
<td>R3↓</td>
<td>L2↓</td>
<td></td>
<td>0.118</td>
</tr>
<tr>
<td>4</td>
<td>L1↑wk</td>
<td>L2↑</td>
<td>R4↓</td>
<td>R3↑</td>
<td>L1↓fl</td>
<td>R1↑B</td>
<td>R2↑</td>
<td>R3↓</td>
<td>L1↓c</td>
<td>L2↓</td>
<td>0.091</td>
</tr>
<tr>
<td>5</td>
<td>L1↑wk</td>
<td>R5↑F</td>
<td>R4↓</td>
<td>R1↑B</td>
<td>R2↑</td>
<td>R3↓</td>
<td>L1↓fl</td>
<td>L1↓c</td>
<td></td>
<td></td>
<td>0.070</td>
</tr>
</tbody>
</table>
Table 10B, a’↓g’

<table>
<thead>
<tr>
<th>T</th>
<th>Seq.1</th>
<th>Seq.2</th>
<th>Seq.3</th>
<th>Seq.4</th>
<th>Seq.5</th>
<th>Seq.6</th>
<th>Seq.7</th>
<th>Seq.8</th>
<th>Seq.9</th>
<th>total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1↑fl</td>
<td>R2↓</td>
<td>R5↓F</td>
<td>L1↓c^a</td>
<td>R1↑B^b</td>
<td>R3↑</td>
<td>R4↑</td>
<td>L1↓wk</td>
<td>0.135</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>L1↑fl</td>
<td>R2↓</td>
<td>R5↓F</td>
<td>R1↑B^b</td>
<td>R3↑</td>
<td>L1↓c^a</td>
<td>R4↑</td>
<td>L1↓wk</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L1↑fl</td>
<td>R5↓F</td>
<td>R2↓</td>
<td>L1↓c^a</td>
<td>R1↑B^b</td>
<td>R3↑</td>
<td>R4↑</td>
<td>L1↓wk</td>
<td>0.080</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>L2↑</td>
<td>L1↑fl</td>
<td>L2↓</td>
<td>R2↓</td>
<td>R5↓F</td>
<td>L1↓c^a</td>
<td>R3↑</td>
<td>R4↑</td>
<td>R1↑B^b</td>
<td>L1↓wk</td>
</tr>
<tr>
<td>5</td>
<td>L1↑fl</td>
<td>R2↓</td>
<td>R5↓F</td>
<td>R1↑B^b</td>
<td>R3↑</td>
<td>L1↓c^a</td>
<td>R4↑</td>
<td>L1↓wk</td>
<td>0.075</td>
<td></td>
</tr>
</tbody>
</table>

Results, Conclusions, and Recommendations for further study

The BCMS proved to be a useful tool for determining which finger moved later than the others in a fingering change. It revealed that certain movements by the author were less coordinated than others. Lifting the fingers generally was less accurate than pressing them. Also confirmed was that thumb movements were often responsible for faulty coordination, especially in the left thumb when it was pressing the whisper key and had to roll to press the c^# key. The faultiest coordination occurred in the following tested intervals (total transition times shown in seconds):

1. g’↑a’ ....... 0.230  
2. a’↓g’ ....... 0.135  
3. d↓c^# ....... 0.118  
4. g↓f..........0.087  
5. c^#↑d..........0.081  
6. d^#↓c^# .......0.081

Through the interpretation of the BCMS data and the ideas from the research connected to the project, the author made several changes to her playing and incorporated a lengthened daily scale routine. Two position changes were made: the
bocal was turned slightly more towards the right in order to play with a straighter right wrist, and the right foot was raised in order to improve balance of the instrument. The author also became aware that her left forearm was often overly tense, inhibiting the movements of her left fingers, leading her to develop the habit of monitoring the muscle tension of this arm, and of holding it slightly further away from the body.

In order for the BCMS to be useful as originally intended for daily practice, a method would have to be found to minimize the amount of finger pressure required to hold the keys or levers near the tone holes closed. A useful enhancement to the device would be to measure the pressure being exerted by the player on each individual key, so that the player could attempt to lessen any overly heavy pressing. Devices called pressure transducers are available for this type of measurement, but none could be found that were thin enough to allow the fingers to cover the tone holes. Ideally, these pressure transducers would be round with holes in their centers to fit around the tone holes, allowing the fingers to still cover the holes. The pressure transducers for the rest of the keys would not need the holes, however.

Another drawback of the BCMS is that bassoon key work is often highly customized for a particular instrument, and to adapt the BCMS to another bassoon would require that the mounting blocks be rebuilt and the levers be repositioned accordingly.

The BCMS was not designed to measure the amount of half-hole opening of the index finger of the left hand; however, a modification to the device to do so could
prove quite useful to the bassoonist who is trying to learn to finger the different opening required for each of the half-hole notes more accurately.

Another useful enhancement to the BCMS would be to find a method of providing audio replay coordinated to the data file so that it would be evident how much poor coordination would actually be noticeable to the listener.

An alternative way of determining the exact nature of a poorly coordinated fingering change might be to make use of digital sound editing equipment. This type of equipment allows the constantly sampled sound to be graphically represented on the computer screen. When an aural distortion indicates that a fingering problem has occurred, the sound could be closely examined on the screen to determine the precise cause. If the player inadvertently added an extra note when more than one finger was lifted, this would be shown on the screen. In the previously mentioned fingering change from Bᵇ to B, (see page 57) an A would be heard if the right thumb was lifted before the right middle finger, but a different type of distortion would be heard if the right middle finger was lifted before the thumb. Two advantages in using digital sound editing equipment would be that it would not require any type of device to be hooked up to the bassoon and it would allow for many "instant replays" of a coordination problem. This type of device would be most useful if it could also be made to display pitch names, as the BCMS was able to do. This would be the ultimate way to "hear it better" as Arthur Weisberg suggested.
Perhaps the general idea for the BCMS or for Callahan's modified clarinet could be tried on other woodwind instruments in the future in order to determine the finger coordination problems encountered on them.
VIII. DISCUSSION OF FANTASY FOR BASSOON BY MALCOLM ARNOLD

Malcolm Arnold’s *Fantasy for Bassoon, Op. 86*, a work for unaccompanied bassoon, was chosen for practice and performance for the project because of the fast tempos and the many finger coordination problems it presents to the bassoonist. Because the work is unaccompanied, any poor coordination would be clearly evident. It is one of a small number of twentieth-century unaccompanied works for the bassoon that has become a standard part of the repertoire.

The British composer, Malcolm Arnold (b. 1921) attended the Royal College of Music on scholarship, where he studied composition and trumpet. He performed as principal trumpet with the London Philharmonic Orchestra from 1942 until 1948, except for two years of war service. After winning the Mendelssohn scholarship in 1948, he turned to composition, writing eight symphonies, two operas, five ballets, fifteen solo concertos, a number of large vocal works, over eighty film scores, including *The Bridge on the River Kwai*, and a variety of works for smaller ensembles, including the well-known wind quintet, *Three Shanties*. The *Fantasy*, dating from 1966, is one of eight works for solo wind instruments, all with the same title, composed between 1965 and 1967. It was composed for the 1966 Birmingham International Wind

---


Competition on commission from the City of Birmingham (England) Symphony Orchestra.80 The piece was also used in the 1990 Gillet Competition sponsored by the International Double Reed Society. The duration of the work is approximately 5 minutes, and the range is from BB to b:

Primarily in the key of B, Fantasy is constructed in sections of varying tempos and moods. It opens with a playful Allegretto, in 2/4 time, in which one of the primary motives is immediately presented, the ascending staccato four-note major scale passage which ends with a surprise half step. This is later extended by the composer into the complete major scale.

One of the most difficult measures of the entire work (example 1) occurs shortly after the opening material, in which two sets of sextuplets in a descending e minor seventh arpeggio appear. This requires the bassoonist to use the alternate G key, operated by the right hand little finger for the two Gs that follow the Bs. The passage ends in a difficult low register maneuver for the left hand thumb and little finger between the notes E and D. While the left thumb moves from the low D key to the low C key, the left little finger must roll from its lower key to its higher one. The author believes that this passage was one that necessitated motor programming.

---

One of the recurring motives is the descending seventh chord arpeggio. This occurs at first with the arpeggios separated by longer notes, and later with a set of three difficult arpeggios in a group (example 2), which again requires the use of the alternate F♯ key. Because of the speed of the arpeggios, the bassoonist may choose to omit the use of the whisper key before the “flick” note that starts the next arpeggio so that the flick key may be reached by the thumb in time.

The next tempo section of the work, in 3/4 time, is marked Allegro non troppo. The mood becomes somewhat wistful and more subdued than the opening section. Here, the composer makes extensive use of the seventh chord arpeggio, both ascending and descending. This section is followed by a return to the opening tempo and
material, with elaboration and extension of the motives, including a difficult descending passage which progresses from sixteenth notes to sextuplet sixteenths, ending in the low register in thirty-second notes (example 3).

Example 3, measures 84-86

Immediately following this is a brief passage of descending octave jumps (example 4) that requires the player to quickly engage the whisper key lock and disengage it after two measures, with only an eighth-note rest for each operation. The whisper key lock is an auxiliary key operated by either the left thumb or the right thumb, depending on the particular model of bassoon being played. The passage would be much more difficult to perform on an instrument lacking the whisper key lock because the left thumb would be required to jump quickly from the whisper key to the appropriate key on the long joint of the bassoon used for the low register notes of the octave jumps, then back to the whisper key for the next high note.

Example 4, measures 88-90
The next tempo is a *presto*, in 2/4 time which begins with the descending seventh arpeggios, at first, staccato, then slurred. This is another of the most technically difficult sections of the piece, because it involves rapid use of the left thumb flick keys, the whisper key, and the C♯ key (example 5).

Example 5, measures 115-118

Near the end of this section is a particularly awkward trill for the left hand index finger, from e to f. Because the base of this finger is involved in the balance of the bassoon, it is quite difficult the attain the quick motion that is needed here. The author was able to attain a faster trill by temporarily removing the weight of the bassoon from the usual balance point at the base of the left index finger for the duration of the trill.

Another difficulty in the section is the frequently encountered interval, low E♭ to G♭, in which the right thumb must quickly move from the pancake key to the key just below it. This movement is more difficult on bassoons which do not have rollers between these two keys.
Also in the *presto*, after the trill, is an interesting section of sixteenths beginning with an f minor arpeggio and continuing with a descending scale passage. There are two statements of the same material, however, the second statement of it is offset rhythmically by one sixteenth note. Arnold has built in one of the traditional practice strategies, that of working on a passage by starting on different notes of the pattern.

The final section of the piece is a *lento*, which presents few finger coordination problems, but serves the compositional purpose of relaxation and closure for the piece. In it, Arnold makes effective use of rhythmic augmentation of a fragment from the opening material.

In learning the work, the author found the following strategies to be most helpful.

1. Decide upon fingerings early in the process of learning the work, and mark them in the part. This includes decisions as to when to use alternate fingerings for speed and when to leave the whisper key earlier than normal in order to reach a flick key on time.

2. When it can be determined that a finger is moving slower than the rest in a transition, move the slow finger first, then the rest of the fingers and gradually shorten the gap until the movement is coordinated. The author was aided in finding the finger responsible for faulty coordination from the analysis of the BCMS data, by recalling the tendencies of the thumbs or certain fingers to be late, and by remembering that finger lifting is likely to be slower than finger pressing.
3. Keep the fingers as close to the keys as possible, even to the point of letting the little fingers remain in contact with their keys. This strategy keeps the other fingers closer to the instrument and allows for greater speed.

4. Work on passages of rapid sixteenth notes in various rhythms, such as triplets and the two types of dotted rhythms, and practice by starting on different notes of the passage.

5. Isolate short sections of notes to practice and combine the sections until the whole passage is learned. Work on the most difficult section first.

6. Practice in front of a mirror. This is another useful way to monitor the height the fingers are being lifted, and to notice if any undesired motions are occurring, such as slipping off a tone hole inadvertently or half-holing one sixteenth too early.
Key Assignments to Input Ports

L1, low BB\textsuperscript{b} (A7)
L1, low BB (A6)
L1, low C (A5)
L1, low D (A4)
L1, b/c' flick (A0)
L1, high d''
L2, e hole (B3)
L1, a/b\textsuperscript{b} flick (A1)
L3, d hole (B2)
L1, c\# (A2)
L1, whisp. (A3)
L4, c hole (B1)
L5, low E\textsuperscript{b} (B0)
L5, low D\textsuperscript{b} (C7)
R1, B\textsuperscript{b} (B7)
R1, low E (B6)
R1, F\# (B5)
R1, alt. A\textsuperscript{b} (B4)
R2, B hole (C6)
R3, A hole (C5)
R4, G (C4)
R5, F (C3)
R5, alt. F\# (C2)
R5, A\textsuperscript{b} (C1)

L1 - Left Thumb
L2 - Left Index Finger
L3 - Left Middle Finger
L4 - Left Ring Finger
L5 - Left Little Finger
R1 - Right Thumb
R2 - Right Index Finger
R3 - Right Middle Finger
R4 - Right Ring Finger
R5 - Right Little Finger
MUSICAL INSTRUMENT INTERFACE BOARD DIAGRAM

+5 VOLTS

FUSE 52 OHMS

PULL UP RESISTORS

3.3 K OHMS

KEY SWITCHES

PORT A INPUTS (8)

PORT B INPUTS (8)

PORT C INPUTS (8)

+5 VOLTS RETURN
Mounting of the BCMS to the Bassoon

- Switch Block Mounting Board
- Switch
- Switch Block
- Hole
- Bassoon
- Switch Actuator Lever (Stiff Wire Bent to Shape)
PROGRAM \OLDBAS\\BASOON.BAS
PROGRAMMED BY ROBERT E. MCNABB, 21 MAY 1995

CLS
PRINT "THE PURPOSE OF THIS PROGRAM IS TO MONITOR THE ELAPSED
TIME"
PRINT "BETWEEN SWITCH CLOSURES ON SWITCHES ATTACHED TO EACH
FINGER"
PRINT "OR KEY OF THE BASSOON."

'  DEFINITION OF VARIABLES
'  REPARED BY ROBERT E. MCNABB 22 MAY 1955

'  CHRS(67)  CAPITAL C LETTER
'  CHRS(68)  CAPITAL D LETTER
'  CHRS(76)  CAPITAL L LETTER
'  CHRS(78)  CAPITAL N LETTER
'  CHRS(80)  CAPITAL P LETTER
'  CHRS(82)  CAPITAL R LETTER
'  CHRS(83)  CAPITAL S LETTER
'  CHRS(85)  CAPITAL U LETTER
'  CHRS(88)  CAPITAL X LETTER

'  ETIME!  ELAPSED TIME (DURATION OF KEY COMBINATION
PLAYED)

'  IA(NDX)  BINARY VALUE OF PORT A FOR INDEXED BIT
'  IB(NDX)  BINARY VALUE OF PORT B FOR INDEXED BIT
'  IC(NDX)  BINARY VALUE OF PORT C FOR INDEXED BIT

'  IAPRT(ILNO)  INDEXED DIGITAL VALUE OF PORT A
'  IBPRT(ILNO)  INDEXED DIGITAL VALUE OF PORT B
'  ICPRT(ILNO)  INDEXED DIGITAL VALUE OF PORT C

'  IBIT  BINARY VALUE USED DIGITAL TO BINARY CONVERSION
'  ICOUNT!  INTERATION COUNT NUMBER
'  ICOUNTER!(ILNO)  LINE NUMBER COUNTER
'  IDATA  INPUT DATA FROM PORTS A, B AND C
'  IFIRSTLNO  FIRST LINE FOR PRINTING OR DISPLAY
'  ILASTLNO  LAST LINE FOR PRINTING OR DISPLAY
'  ILMNO  PRINTER, DISPLAY OR DISK STORAGE LINE NUMBER
'  ILLNOLAST  LAST LINE STORED IN RAM

'  INP(&H300)  INPUTS PORT A
' INP(&H301) INPUTS PORT B
' INP(&H302) INPUTS PORT C
' IPAOLD OLD VALUE OF PORT A INPUT
' IPBOLD OLD VALUE OF PORT B INPUT
' IPCOLD OLD VALUE OF PORT C INPUT
' KDIFF PRESENT VALUE DIFFERENT FROM PREVIOUS VALUE
' KEY(14) DOWN ARROW ON NUMERIC KEYBOARD
' KPIA(INDX) INDEXED DIGITAL VALUES OF PORT A NOTE
' KPIB(INDX) INDEXED DIGITAL VALUES OF PORT B NOTE
' KPIA(INDX) INDEXED DIGITAL VALUES OF PORT C NOTE
' KPADATA DIGITAL VALUE OF PORT A INPUT TO DETERMINE
' KPBDATA DIGITAL VALUE OF PORT B INPUT TO DETERMINE NOTE
' KPCDATA DIGITAL VALUE OF PORT C INPUT TO DETERMINE NOTE
' KPIDX INDEX FOR USE IN DETERMINING NOTE PLAYED
' NDX INDEX
' NOTES NOTE PLAYED (* INDICATES UNKNOWN)
' OPIN OPERATOR INPUT VARIABLE
' PITCHS(I) NAME OF NOTE PLAYED
' SCAFC SCALE FACTOR TO CONVERT NUMBER OF
' INTERACTIONS TO ELAPSED TIME

'TYPE DEFINITION
DEFINT L, K
DEFSTR O-P

'DIMENSION VARIABLES STORED FOR DISPLAY AND PRINTOUT
DIM ICOUNTER!(5000), LAPRT(5000), IBPRT(5000), ICPRT(5000)

'DEFINE DATA FORMAT
FMTS = "##### #### # # # # # # # # # # # # # # # # #" 

DEF IN E SCALE FACTOR TO CONVERT COUNTS TO TIME.  
THIS VALUE IS UNIQUE TO EACH MACHINE TYPE.  
SCA FC = .00011865# 

SET UP DIGITAL INPUT CARD TO READ PORTS A, B AND C 
ASSUME PIO DEVICE BASE ADDRESS IS &H300.  
OUT (&H300), &H9B 

ENABLE TRAPPING OF DOWN ARROW KEY TO STOP DATA TAKING 
KEY(14) ON 

**PITCH TABLE** 

<table>
<thead>
<tr>
<th>KEY</th>
<th>KPIT A(1)</th>
<th>KPIT B(1)</th>
<th>KPIT C(1)</th>
<th>PITCHS(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>240</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW Bb&quot;</td>
</tr>
<tr>
<td>1</td>
<td>112</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW B&quot;</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW C&quot;</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW Db&quot;</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW D wk&quot;</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW Eb wk&quot;</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW Eb no wk&quot;</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW E wk&quot;</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>78</td>
<td>120</td>
<td>&quot;LOW E no wk&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEY</th>
<th>KPIT A(11)</th>
<th>KPIT B(11)</th>
<th>KPIT C(11)</th>
<th>PITCHS(11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>8</td>
<td>14</td>
<td>120</td>
<td>&quot;LOW F&quot;</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>120</td>
<td>&quot;LOW F# th&quot;</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>8</td>
<td>124</td>
<td>&quot;LOW F# alt&quot;</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>8</td>
<td>112</td>
<td>&quot;LOW G&quot;</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>114</td>
<td>&quot;LOW Ab&quot;</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>8</td>
<td>30</td>
<td>112</td>
<td>&quot;LOW Ab alt&quot;</td>
</tr>
<tr>
<td>17</td>
<td>8</td>
<td>14</td>
<td>96</td>
<td>&quot;LOW A&quot;</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>142</td>
<td>&quot;Bb&quot;</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>8</td>
<td>14</td>
<td>64</td>
<td>&quot;B&quot;</td>
</tr>
<tr>
<td>20</td>
<td>8</td>
<td>14</td>
<td>0</td>
<td>&quot;C&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEY</th>
<th>KPIT A(21)</th>
<th>KPIT B(21)</th>
<th>KPIT C(21)</th>
<th>PITCHS(21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>28</td>
<td>14</td>
<td>0</td>
<td>&quot;C#&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KEY</th>
<th>KPIT A(22)</th>
<th>KPIT B(22)</th>
<th>KPIT C(22)</th>
<th>PITCHS(22)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>8</td>
<td>12</td>
<td>0</td>
<td>&quot;D&quot;</td>
</tr>
<tr>
<td>KPIT.A(23)</td>
<td>KPIT.B(23)</td>
<td>KPIT.C(23)</td>
<td>PITCHS(23)</td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(24)</td>
<td>KPIT.B(24)</td>
<td>KPIT.B(24)</td>
<td>PITCHS(24)</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(26)</td>
<td>KPIT.B(26)</td>
<td>KPIT.C(26)</td>
<td>PITCHS(26)</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(27)</td>
<td>KPIT.B(27)</td>
<td>KPIT.C(27)</td>
<td>PITCHS(27)</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(28)</td>
<td>KPIT.B(28)</td>
<td>KPIT.C(28)</td>
<td>PITCHS(28)</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(29)</td>
<td>KPIT.B(29)</td>
<td>KPIT.C(29)</td>
<td>PITCHS(29)</td>
<td></td>
</tr>
<tr>
<td>KPIT.A(30)</td>
<td>KPIT.B(30)</td>
<td>KPIT.C(30)</td>
<td>PITCHS(30)</td>
<td></td>
</tr>
</tbody>
</table>

| KPIT.A(31) | KPIT.B(31) | KPIT.C(31) | PITCHS(31) |
| KPIT.A(32) | KPIT.B(32) | KPIT.C(32) | PITCHS(32) |
| KPIT.A(33) | KPIT.B(33) | KPIT.C(33) | PITCHS(33) |
| KPIT.A(34) | KPIT.B(34) | KPIT.C(34) | PITCHS(34) |
| KPIT.A(35) | KPIT.B(35) | KPIT.C(35) | PITCHS(35) |
| KPIT.A(36) | KPIT.B(36) | KPIT.C(36) | PITCHS(36) |
| KPIT.A(37) | KPIT.B(37) | KPIT.C(37) | PITCHS(37) |
| KPIT.A(38) | KPIT.B(38) | KPIT.C(38) | PITCHS(38) |
| KPIT.A(39) | KPIT.B(39) | KPIT.C(39) | PITCHS(39) |
| KPIT.A(40) | KPIT.B(40) | KPIT.C(40) | PITCHS(40) |

| KPIT.A(41) | KPIT.B(41) | KPIT.C(41) | PITCHS(41) |
| KPIT.A(42) | KPIT.B(42) | KPIT.C(42) | PITCHS(42) |
| KPIT.A(43) | KPIT.B(43) | KPIT.C(43) | PITCHS(43) |
| KPIT.A(44) | KPIT.B(44) | KPIT.C(44) | PITCHS(44) |
| KPIT.A(45) | KPIT.B(45) | KPIT.C(45) | PITCHS(45) |
| KPIT.A(46) | KPIT.B(46) | KPIT.C(46) | PITCHS(46) |
| KPIT.A(47) | KPIT.B(47) | KPIT.C(47) | PITCHS(47) |
| KPIT.A(48) | KPIT.B(48) | KPIT.C(48) | PITCHS(48) |
| KPIT.A(49) | KPIT.B(49) | KPIT.C(49) | PITCHS(49) |
| KPIT.A(50) | KPIT.B(50) | KPIT.C(50) | PITCHS(50) |
| KPIT.A(51) | KPIT.B(51) | KPIT.C(51) | PITCHS(51) |
| KPIT.A(52) | KPIT.B(52) | KPIT.C(52) | PITCHS(52) |
| KPIT.A(53) | KPIT.B(53) | KPIT.C(53) | PITCHS(53) |
| KPIT.A(54) | KPIT.B(54) | KPIT.C(54) | PITCHS(54) |
| KPIT.A(55) | KPIT.B(55) | KPIT.C(55) | PITCHS(55) |
| KPIT.A(56) | KPIT.B(56) | KPIT.C(56) | PITCHS(56) |
| KPIT.A(57) | KPIT.B(57) | KPIT.C(57) | PITCHS(57) |
| KPIT.A(58) | KPIT.B(58) | KPIT.C(58) | PITCHS(58) |
| KPIT.A(59) | KPIT.B(59) | KPIT.C(59) | PITCHS(59) |
| KPIT.A(60) | KPIT.B(60) | KPIT.C(60) | PITCHS(60) |

KPIT.A(61) = 0; KPIT.B(61) = 139; KPIT.C(61) = 82; PITCHS(61) = "High C#"
KPITA(62) = 0; KPITB(62) = 131; KPITC(62) = 18; PITCHS(62) = "High D"
KPITA(63) = 0; KPITB(63) = 131; KPITC(63) = 0; PITCHS(63) = "High Eb"
KPITA(64) = 0; KPITB(64) = 130; KPITC(64) = 82; PITCHS(64) = "High E"
PITCHS(65) = "*"
KPND\MAX = 65

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

' SET UP TO RUN PROGRAM
100    CLS
PRINT "    BASSOONIST'S COORDINATION MEASUREMENT SYSTEM": PRINT
PRINT "    MAIN MENU": PRINT
PRINT "    ENTER (R) TO RUN PROGRAM": PRINT
PRINT "    ENTER (S) TO SAVE PROGRAM DATA": PRINT
PRINT "    ENTER (L) TO LOAD PROGRAM DATA FILE": PRINT
PRINT "    ENTER (D) TO REVIEW DATA": PRINT
PRINT "    ENTER (P) TO PRINT SELECTED DATA": PRINT
INPUT "    ENTER SELECTION FROM MENU": OPIN
IF (OPIN = CHR$(82)) GOTO 200    'RUN PROGRAM
IF (OPIN = CHR$(83)) GOTO 1600    'SAVE DATA
IF (OPIN = CHR$(68)) GOTO 1700    'REVIEW DATA
IF (OPIN = CHR$(80)) GOTO 1240    'PRINT DATA
IF (OPIN = CHR$(76)) GOTO 1800    'LOAD DATA FILE
GOTO 100
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

'INITIALIZATION SECTION

'SET INITIAL INPUT VALUES = 255 (ONE'S COMPLEMENT OF ZERO)

200    IPAOLD = 255: IPBOLD = 255: IPCOLD = 255
'SET PRINTER LINE NUMBER = 0
ILNO = 1

'SET INTERACTION COUNTER = 0
ICOUNT = 0

'SET DIFFERENCES BETWEEN READINGS = 0
KDIFF = 0

'PROVIDE INSTRUCTIONS TO PERFORMER (NEW 5/21)
CLS: PRINT "    PLEASE PLAY NOW."; PRINT
PRINT "DEPRESS DOWN ARROW ON NUMERIC KEYBOARD TO SEE DATA."

' START OF ITERATIVE SECTION
DATA ACQUISITION SECTION
THIS SECTION ACQUIRES DATA FROM THE PPI PIO 1/0 DEVICE AND COMPARES THE DATA WITH THE PREVIOUS VALUES. IF THERE IS A CHANGE, THE ELAPSED NUMBER OF COUNTS IS STORED IN RAM TO DETERMINE THE ELAPSED TIME FOR DISPLAY, DISK STORAGE OR PRINT OUT. SIMILARLY, DECIMAL VALUES FOR THE PORT INPUTS ARE STORED IN RAM FOR LATER USE.

INCREMENT COUNTER
500 ICOUNT! = ICOUNT! - 1

' INPUT "COUNT": ICOUNT! TEST ONLY

READ PORTS A, B AND C AND TEST FOR CHANGE

' PORT A
IDATA = INP(&H300)
' INPUT "PORT A = "; IDATA: IDATA = 255 - IDATA TEST ONLY
IF (IDATA = IPAOLD) GOTO 600
KDIFF = 1: IPAOLD = IDATA

' PORT B
600 IDATA = INP(&H301)
' INPUT "PORT B = "; IDATA: IDATA = 255 - IDATA TEST ONLY
IF (IDATA = IPBOLD) GOTO 650
KDIFF = 1: IPBOLD = IDATA

' PORT C
650 IDATA = INP(&H302)
' INPUT "PORT C = "; IDATA: IDATA = 255 - IDATA TEST ONLY
IF (IDATA = IPCOLD) GOTO 660
KDIFF = 1: IPCOLD = IDATA

'MEASUREMENT STOPS IF DOWN ARROW KEY IS DEPRESSED. (NEW 5/21)
660 ON KEY(14) GOSUB 2000
IF (KDIFF = 0) GOTO 500

'SAVE SWITCH CHANGE DATA
680  ICOUNT! = ICOUNT! 
    IAPRTILNO) = IPAOLD 
    IBPRTILNO) = IPBOLD 
    ICPRT! = IPCOLD 
    ILNOLAST = ILNO  'LAST LINE STORED IN RAM 
    ILASTLNO = ILNO  'LAST LINE TO BE PRINTED AFTER FINGERS 
UP
    IFIRSLNO = ILNOLAST - 18 
    IF (IFIRSLNO < 1) THEN IFIRSLNO = 1 
'RESET COUNTER AND DIFFERENT INPUT SWITCH 
    ICOUNT! = 0 
    KD!FF = 0 
'TRANSMIT LINE COUNTER 
    ILNO = ILNO - 1 
    GOTO 500 
END 

' *********************** DIGITAL TO BINARY CONVERSION SUBROUTINE 
'PORT A
800  IDATA = 255 - IPAOLD: KPADATA = IDATA  'USED TO DETERMINE PITCH 
    IBIT = 128 
    FOR NDX = 1 TO 8: IA(NDX) = 1: NEXT 
    FOR NDX = 1 TO 7 
    IF (IDATA < IBIT) THEN IA(NDX) = 0 ELSE IDATA = IDATA - IBIT 
    IBIT = IBIT / 2 
NEXT 
    IA(8) = IDATA 

'PORT B 
    IDATA = 255 - IPBOLD: KPBDATA = IDATA  'USED TO DETERMINE PITCH 
    IBIT = 128 
    FOR NDX = 1 TO 8: IB(NDX) = 1: NEXT 
    FOR NDX = 1 TO 7 
    IF (IDATA < IBIT) THEN IB(NDX) = 0 ELSE IDATA = IDATA - IBIT 
    IBIT = IBIT / 2 
NEXT 
    IB(8) = IDATA 

'PORT C 
    IDATA = 255 - IPCOLD: KPCDATA = IDATA  'USED TO DETERMINE PITCH
IBIT = 128
FOR NDX = 1 TO 8: IC(NDX) = 1: NEXT
FOR NDX = 1 TO 7
    IF (IDATA < IBIT) THEN IC(NDX) = 0 ELSE IDATA = IDATA - IBIT
    IBIT = IBIT / 2
NEXT
IC(8) = IDATA
RETURN
END

************

*NOTE DETERMINATION SUBROUTINE
850  KPIDNX = 1

'COMPARE PITCH DATA INPUT WITH PITCH TABLE
900  IF ((KPADATA = KPITA(KPIDX)) AND (KPBDATA = KPITB(KPIDX))
     AND (KPCDATA = KPITC(KPIDX))) THEN GOTO 920 ELSE GOTO 910
910  KPIDNX = KPIDNX - 1
     IF KPIDNX < KPIDNX MAX GOTO 900
920  NOTES = PITCHS(KPIDX)
     RETURN
END

************

'SEND DATA TO PRINTER SUBROUTINE FOLLOWS:
1240  CLS
1241  PRINT "LAST LINE NUMBER IN FILE = "; ILNOLAST
     PRINT "ENTER NUMBER OF FIRST LINE TO BE PRINTED": IFIRSLNO
     IF (IFIRSLNO > ILNOLAST) THEN GOTO 1242 ELSE GOTO 1243
1242  PRINT "OUT OF RANGE": PRINT : GOTO 1241
1243  PRINT "ENTER NUMBER OF LAST LINE TO BE PRINTED": ILASTLNO
     IF (ILASTLNO > ILNOLAST) THEN ILASTLNO = ILNOLAST
     PRINT "SEND HEADER TO PRINTER"
1245  LPRINT "LINE PORT A PORT B PORT C PITCH"
     LPRINT " NO. ETIME 765 432 10 765 432 10 765 432 10"
     LPRINT :
     LPRINT " L L L W M A B P F A E D C L B A G F A A T"
     LPRINT " O O O O H I / / b A = L O O L b E"
     LPRINT " W W W I D B C N T H H H W W H H K T S"
     LPRINT " S b C O O O O O E K T"
     LPRINT " B B C D P C F A B L L L E D L L Y Y F E"
     LPRINT " b E = F L K b E E e b E E = Y"
FOR ILNO = IFIRSTNO TO ILASTNO

'CONVERT DIGITAL TO BINARY FOR PRINTOUT

IPAOLD = IAPRT(ILNO)
IPBOLD = IBPRT(ILNO)
IPCOLD = ICPRT(ILNO)

'CONVERT DIGITAL TO BINARY
GOSUB 800

'DETERMINE NOTE PLAYED
GOSUB 850

'CALCULATE ETIME FOR PRINT OR DISPLAY
ETIME! = ICONTNR((ILNO + 1) * SCAFC !

'TLNO - 1 IS USED TO PUT THE ELAPSED TIME ON THE SAME LINE
'AS THE NOTE PLAYED

'TEST TO SEE IF LINE NUMBER PLUS 1 IS WITHIN MEASUREMENT RANGE
'AN ETIME! OF 999.999 INDICATES THAT THIS TIME IS NOT VALID
IF (ILNO + 1 > ILNOLAST) THEN ETIME! = 999.999

'SEND DATA LINES TO PRINTER

1310 LPRINT USING FMTS; ILNO; ETIME!; LA(1); LA(2); LA(3); LA(4); LA(5); LA(6); LA(7); LA(8); IB(1); IB(2); IB(3); IB(4); IB(5); IB(6); IB(7); IB(8); IC(1); IC(2); IC(3); IC(4); IC(5); IC(6); IC(7); IC(8); SPC(2);
LPRINT NOTES
NEXT
ILNO = 0
1320 GOTO 100
END

'DATA SAVE SUBROUTINE FOLLOWS:

1600 CLS : PRINT "DATA SAVE SUBROUTINE"
INPUT "ENTER OUTPUT DATA \OLDBAS\FILENAME.DAT "; FILESPECS
OPEN FILESPECS FOR OUTPUT AS #1
WRITE #1, ILNOLAST
FOR ILNO = 1 TO ILNOLAST
WRITE #1, IAPRT(ILNO), IBPRT(ILNO), ICPRT(ILNO)
NEXT
CLOSE #1
GOTO 100

• DATA REVIEW SUBROUTINE FOLLOWS
1700  GOSUB 1900  'CALL PRINT SUBROUTINE

' NAVIGATE THROUGH DATA TABLE
1710  INPUT "DEPRESS ENTER KEY": OPIN
       PRINT "ENTER (C) TO RESUME DATA TAKING"
       PRINT "ENTER (U) TO PAGE UP 5 LINES"
       PRINT "ENTER (L) TO PAGE UP 20 LINES"
       PRINT "ENTER (R) TO PAGE DOWN 20 LINES"
       PRINT "ENTER (D) TO PAGE DOWN 5 LINES"
       PRINT "ENTER (N) TO SELECT NEW STARTING LINE"
       PRINT "ENTER (X) TO RETURN TO MAIN MENU": PRINT
       INPUT "ENTER SELECTION FROM MENU": OPIN
       IF (OPIN <> CHRS(67)) THEN GOTO 1720  'RESUME DATA TAKING
       GOTO 680

1720  IF (OPIN <> CHRS(85)) THEN GOTO 1730  'PAGE UP 5 LINES
       IFIRSTNO = IFIRSTNO - 5
       ILASTLNO = IFIRSTNO - 20
       GOSUB 1900
       GOTO 1710

1730  IF (OPIN <> CHRS(76)) THEN GOTO 1740  'PAGE UP 20 LINES
       IFIRSTNO = IFIRSTNO - 20
       IF (IFIRSTNO < 1) THEN IFIRSTNO = 1
       ILASTLNO = IFIRSTNO - 20
       IF (ILASTLNO > ILNOLAST) THEN ILASTLNO = ILNOLAST
       GOSUB 1900
       GOTO 1710

1740  IF (OPIN <> CHRS(82)) THEN GOTO 1750  'PAGE DOWN 20 LINES
       IFIRSTNO = IFIRSTNO - 20
IF (IFIRSLNO > (ILNOLAST - 20)) THEN IFIRSLNO = ILNOLAST - 20
IF (IFIRSLNO < 1) THEN IFIRSLNO = 1
ILASTLNO = IFIRSLNO - 20
IF (ILASTLNO > ILNOLAST) THEN ILASTLNO = ILNOLAST
GOSUB 1900
GOTO 1710

1750 IF (OPIN <> CHR$(68)) THEN GOTO 1760  'PAGE DOWN 5 LINES
   IFIRSLNO = IFIRSLNO - 5
   ILASTLNO = IFIRSLNO - 20
   GOSUB 1900
   GOTO 1710

1760 IF (OPIN <> CHR$(78)) THEN GOTO 1780  'START ON NEW LINE
   CLS : PRINT "LAST LINE NUMBER IN FILE = "; ILNOLAST
1770 INPUT "ENTER NUMBER OF FIRST LINE TO BE VIEWED "; IFIRSLNO
   IF (IFIRSLNO < (ILNOLAST - 20)) THEN GOTO 1775
   IFIRSLNO = ILNOLAST - 20
1775 ILASTLNO = IFIRSLNO - 20
   GOSUB 1900
   GOTO 1710

1780 IF (OPIN = CHR$(88)) THEN GOTO 100  'GO TO MAIN MENU
   ILNO = ILNOLAST
   GOTO 1710
END

'******************************************************************************
'DATA FILE INPUT SUBROUTINE GOES HERE
1800 CLS : PRINT "LOAD DATA FILE FROM DISK SUBROUTINE": PRINT
   PRINT "WARNING: THIS DATA WILL OVERRIDE EXISTING DATA IN RAM."
   INPUT "ENTER C TO CONTINUE, ELSE ANY OTHER KEY TO STOP.": OPIN
   IF (OPIN = CHR$(67)) THEN GOTO 1810 ELSE GOTO 100
1810 PRINT : INPUT "ENTER INPUT DATA \OLDBAS\FILENAME.DAT "; FILESPCS
   OPEN FILESPCS FOR INPUT AS #1
   INPUT #1, ILNOLAST
   FOR ILNO = 1 TO ILNOLAST
      INPUT #1, ICOUNTERI(ILNO), IAPRT(ILNO), IBPRT(ILNO), ICPRT(ILNO)
   NEXT
   CLOSE #1
GOTO 100
END

PRINT DATA TO SCREEN SUBROUTINE
PRINT HEADER TO SCREEN

1900  CLS
PRINT "LINE PORT A PORT B PORT C PITCH"
PRINT "NO. ETIME 76543210 76543210 76543210"

IF (IFIRSLNO < 1) THEN IFIRSLNO = 1 "TEST FOR PRINT IN LOWER RANGE"
IF (ILASTLNO > ILNOLAST) THEN ILASTLNO = ILNOLAST "TEST FOR PRINT IN UPPER RANGE"

PRINT DATA LINES TO SCREEN
FOR ILNO = IFIRSLNO TO ILASTLNO
ETIME! = ICOUNTER(ILNO) * SCAFCl
IF ((ILNO - 1) > ILNOLAST) THEN ETIME! = 999.999 "NEW 5/21 ETIME! OF 999.999 INDICATES THAT THE DATA IS NOT VALID."
PRINT NOTES
NEXT

RETURN

'CONVERT DIGITAL TO BINARY FOR PRINTOUT
IPAOLD = LAPRT(ILNO)
IPBOLD = IBPRT(ILNO)
IPCOLD = ICPRT(ILNO)

GOSUB 800

'DETERMINE NOTE PLAYED
GOSUB 850

'SEND DATA LINES TO SCREEN
PRINT USING FMTS; ILNO; ETIME!; PA(1); PA(2); PA(3); PA(4); PA(5); PA(6); PA(7); PA(8); PB(1); PB(2); PB(3); PB(4); PB(5); PB(6); PB(7); PB(8); PC(1); PC(2); PC(3); PC(4); PC(5); PC(6); PC(7); PC(8); SPC(2);
PRINT NOTES
NEXT
RETURN
END

'STOP TAKING DATA WITH DOWN ARROW SUBROUTINE (NEW 5/21)
2000  KDIFF = 1
RETURN 1700
END
APPENDIX C  FINGERINGS FOR INTERVALS TESTED WITH THE BCMS

1. B - d

2. f - g

3. f - f#

4. B♭ - A♭
REFERENCES

Articles


Books and Dissertations


Dictionaries and Encyclopedias


Music

Almenraeder, Carl, revised P. X. Laube. Scale Exercises in all keys.


Interviews
