Physiology of Wind-Instrument Playing and the Implications for Pedagogy

Marjatta Teirilä

JYVÄSKYLÄ STUDIES IN THE ARTS 66

Marjatta Teirilä

Physiology of Wind-Instrument Playing and the Implications for Pedagogy

Esitetään Jyväskylän yliopiston humanistisen tiedekunnan suostumuksella
julkisesti tarkastettavaksi yliopiston Athenaeum-rakennuksen salissa A103
marraskuun 21. päivänä 1998 klo 12.

Academic dissertation to be publicly discussed, by permission of
the Faculty of Humanities of the University of Jyväskylä,
in the Building Athenaeum, Auditorium A103, on November 21, 1998 at 12 o'clock noon.

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 1998

Physiology of Wind-Instrument Playing and the Implications for Pedagogy

JYVÄSKYLÄ STUDIES IN THE ARTS 66

Marjatta Teirilä

Physiology of Wind-Instrument Playing and the Implications for Pedagogy

UNIVERSITY OF JYVÄSKYLÄ

JYVÄSKYLÄ 1998

Editors
Matti Vainio
Department of Musicology, University of Jyväskylä
Kaarina Nieminen
Publishing Unit, Univesity Library of Jyväskylä

URN:ISBN:978-951-39-9071-8
ISBN 978-951-39-9071-8 (PDF)
ISSN 0075-4633

Cover designed by Tuomo Teirilä, statue by Eila Oksanen

ISBN 951-39-0224-2
ISSN 0075-4633

Jyväskylä University Printing House, Jyväskylä
and ER-Paino Ky, Lievestuore

I dedicate this book to our dog Pulivari who was the best creature on earth and is now in heaven.

ABSTRACT

Teirilä, Marjatta
Physiology of Wind-Instrument Playing and the Implications for Pedagogy
Jyväskylä: University of Jyväskylä, 1998. 117 p.
(Jyväskylä Studies in the Arts,
ISSN 0075-4633; 66)
ISBN 951-39-0224-2
Finnish summary
Diss.

Finnish wind-instrument teachers' knowledge of physiology and their thoughts about its usefulness in pedagogy were mapped by interviewing them. The teachers considered proper breathing to be the basis of a good playing technique. Physiological knowledge was considered to be especially valuable in elementary grade teaching.

Spirometry, intra oral pressure gauging, and measuring the location of breathing with belts constructed for this purpose were the methods to study breathing patterns associated with wind playing. The parameters measured were expenditure of air, blowing pressure, lung volume at the beginning of playing, and the location of breathing. Professional orchestra players and students majoring in wind playing at the Sibelius Academy participated as subjects in this investigation. During wind playing, both the expenditure of air and airway pressure were found to be beyond ordinary physiological limits most of the time. The players preferred low or even location of inspiration preparatory to playing. Especially deep preparatory inspiration was typical of brass players.

EMG-recordings were conducted to get information about the type of muscular work involved in wind playing, singing, and some expulsive events. Professional wind players, singers ,and controls without any experience in wind playing and singing participated in this investigation. The use of muscles during wind-instrument playing resembled their use during normal expulsive events and singing. The spatial distribution of muscular activity depended on the depth of inspiration before blowing. This phenomenon was independent of former experience in pressure blowing.

Inaccuracies in wind players' intonation were determined by simultaneous, graphical recordings of the changes in intonation, dynamics and airway pressure. The subjects were professional wind players. The failures in intonation were small. The biased tones tended to slide to the direction where the physical effort needed was smallest.

To determine the intonation behaviour and blowing pressure demands of oboe reeds made of natural and artificial cane, electromechanical methods were used. Artificial reeds were lighter to blow but had more troublesome intonation than most natural reeds. However, one natural reed was almost as light to blow as

the artificial reeds, and it had the most logically behaving intonation of all reeds measured.

Adaptation to wind playing was determined by spirometry in student wind-instrumentalists and controls, and by Valsalva testing in experienced professional wind players. Both breathing patterns and Valsalva ratios were changed in the wind players indicating adaptation

Occupational health hazards were mapped by questionary sent to the players of the symphony orchestras in Helsinki. According to the answers, wind players did not suffer more than other players from circulatory or respiratory diseases.

Keywords: physiology, wind-instrument playing, pedagogy, oboe, music, respiration, winds

ACKNOWLEDGEMENTS

This thesis was carried out at the Department of Clinical Physiology, Laakso Hospital, Helsinki; the Department of Physiology, Helsinki University; the Sibelius Academy; and the Institute of Musicology, University of Jyväskylä. For the possibility to work at these institutes and departments I wish to thank their principals: Docent Yrjö Salorinne, Professor Matti Bergström, Professor Dag Stenberg, Professor Olli Jänne, Professor Ellen Urho, Professor Lassi Rajamaa, and Professor Matti Vainio. I am also grateful to the personnel of the above institutes for their assistance and support.

I wish to express my special gratitude to:

Docent Yrjö Salorinne, M.D. whose expertice and guidance were invaluable for me in this work from the beginning to the end. He also patiently taught me the physiological way of thinking which is so important in this kind of investigation.

Professor Dag Stenberg, M.D. who introduced me to the E.G. recording technique and was of precious help when I conducted the recordings in his laboratory.

Dr. Time Huopaniemi who advised me to investigate circulatory reactions in wind players, and taught me the testing methods developed by Kari Tahvanainen to whom I am also indebted.

Mr. Kaarlo Pietikäinen, a retired solo-oboist in the Finnish Radio Symphony Orchestra, and Mr. Asser Sipilä, the late solo-oboist of the Helsinki Philharmonics. They described to me the age-related occupational problems of wind players and demonstrated the importance of reed making.

Mr. Sven-Erik Paananen, the second solo-oboist of the Helsinki Philharmonics and Mr. Jouko Teikari, a former solo-oboist in the Finnish Radio Symphony Orchestra, now teaching oboe playing at the Sibelius Academy. They gave me valuable hints how to gather information about the attitudes of orchestral musicians towards the physiology of playing. They also taught me the reed-measuring methods.

Professor Matti Vainio Ph.D. who incouraged me to complete this work.

Docent Ilkka Linnankoski, Ph.D. under whose linguistic tuition the language of my manuscript started gradually to resemble English.

Mr. Hannu Apajalahti, L.M. who facilitated my work at the Academy by taking my efforts seriously.

Mrs. Kaarina Nieminen who skillfully manipulated the fourth dimension at the final delivery of this thesis.

Mrs. Eila Oksanen, the sculptor, who kindly allowed me to use a photo of her piece of art on the cover of this book.

My husband Tuomo and son Riku who have patiently lived among the chaos created by me and my work. With incredible endurance Tuomo, edited each "final" manuscript. "Nobody knows the trouble they've seen..."

Our dogs Pulivari and Irka who made life worth living even during the gloomest times.

This work was financially supported by Suomen kulttuurirahasto and Wihurin rahasto. I am grateful for them.

CONTENTS

MUSICAL TERMS

Articulation = the way a player starts and stops phrases and single notes.

Bore of an instrument = dimensions of the open inside space of a wind instrument.

Brass instruments = winds usually made of brass, vibrating sound generator is a pair of human lips inside the instrument mouth piece. The brass in a symphony orchestra include: French horn, trumpet, trombone and tuba.

Cane (of an oboe reed) = blades or canes of the reed are normally made of a Mediterranean hey called Arundo Donax. Artificial materials, fibre-glass and plastic, are used too.

Chromatic scale = a musical scale including twelve half steps in an octave.

Circular breathing = permanent breathing = the technique which makes enables breathing without braking long phrases (page 99).

Embouchure = the way the mouthpiece of the instrument is held (wood winds), or the lips are held against the mouth piece (brass instruments).

Examination board = (here) the group of teachers whose duty is to evaluate examination concerts given by music students.

Intermittent breathing = playing one phrase after inspiration and another after expiration, and so on. This is a practical method to enable breathing even during short breathing pauses.

Intonation = the success in reaching a right tune in musical performance: poor intonation = not in tune; good intonation = in tune.

Oboe reed = the mouthpiece of an oboe, made of two canes fixed tight around a metallic tube and finished by modelling the canes so that they can be made vibrate by blowing.

Phrase = musical phrase = the shortest meaningful unit in music that "is saying something".

Scrape = natural canes of an oboe reed are finished with a knife. The manipulated area in the reed is called the scrape.

Slide = the movable part of a trombone, making it possible to change the length and tune of the instrument.

Timbre = tone colour of a sound.

Vibrato = fast fluctuation of a sound, usually slightly changing the pitch and volume, sometimes one or the other.

Woodwind instruments = a term generally used when speaking of the group of symphony winds traditionally made of wood, though nowadays the materials may be something else. For instance, flute is normally made of metal. The saxophone is included to this group of instruments because its mouthpiece is a single reed typical of woodwinds. The material of the body of the instrument has always been metal. The flute, oboe, clarinet, bassoon and saxophone are wood-wind instruments.

The fathers of Finnish oboe teaching, Kaarlo Pietikäinen and Asser Sipilä, have had a great influence on the oboe tradition in this country. They worked as solo oboists in Helsinki, Pietikäinen in the Finnish Radio Symphony Orchestra and Sipilä in the Helsinki Philharmonic Orchestra, and taught, during their active years, all the coming professional oboists in Finland.

C3, E3, G3 and C4 form the C major triad starting from the middle C.

PHYSIOLOGICAL TERMS

Agonist = a prime effector muscle, and another muscle giving more efficiency to the movement.

Anatomy = the science studying the structure of the body and the relation of its parts.

Antagonist = a muscle whose action is the direct opposite to that of another muscle.

Bradycardia = decreased heart rate.

Breathing musculature:
1.proper = primary musculature in normal quiet breathing
2.auxiliary = muscles that help the proper musculature during increased effort.

ECG = electrocardiography = a graphic tracing of the variations in electrical potential caused by the excitation of the heart muscle and detected at the body surface graphically.

EEG = electroencephalograph = the recording of electric currents developed in the brain, usually by means of electrodes applied to the scalp. The instrument can be used, also, in EMG recordings.

EMG = electromyography = an electrodiagnostic technique for recording graphically the electrical activity of skeletal muscles.

FRC-level = functional residual capacity = the volume of the air that is left in the lungs after a quiet expiration.

Hyperventilation = a state of excessive ventilation resulting in reduction of carbon dioxide in blood.

Hypoventilation = a state of reduced ventilation resulting in accumulation of carbon dioxide in blood.

Minute ventilation = the amount of air entering the lungs during one minute.

Pathology = the science that studies the physiological malfunctioning and anatomical malformation associated with diseases.

Physiology = the science that studies the functioning of human body, its organs and tissues.

Pulmonary circulation = circulation in the lungs, the blood flow from the right to the left heart through the lungs.

Spirometry = measuring ventilatory function.

Systemic circulation = circulation in the body when blood is moving from the left to the right heart.

Tachycardia = increased heart rate.

TV = tidal volume = the amount of air entering the lungs during one respiratory cycle.

Valsalva test = the test measuring the autonomic control of circulation.

VC = vital capacity = the maximal amount of air during voluntary inhalation and exhalation.

Venous return = the quantity of blood flowing from the veins into the right atrium each minute.

1 INTRODUCTION

Fritz Rösler begins his book "Oboe-Studies I" (1984) with a chapter "Hints on Practice". There Rösler suggests, to those who are just starting to practise a new piece of music, first to read the music carefully and "then the study can be played through in slow time, with exact control of all the parts of the body involved in order to avoid inexactness." This advice presumes that the physiological functions associated with playing are familiar to players or, at least, that reliable information is available.

In 1978, Alfred Tolksdorf and Fritz Rösler published their "Oboe Tutor I" with excellent pedagogical chapters. Under the titles "Physical Qualifications for Learning the Oboe" and "Breathing Technique" physiological information was given and it was applied to musical purposes in co-operation with Gerd Schneider as a medical adviser.

Conflicting views about the significance of physiological factors in oboe playing can be found for instance in Evelyn Rothwell's "Oboe Technique"(1968), Leon Goossens' and Edwin Roxburgh's "Oboe" (1977), Philip Bate's "The Oboe" (1975), David Ledet's "Reed Styles" (1981), and Robert Sprenkle's and David Ledet's "The Art of Oboe Playing" (1961). Opinions differ as to the breathing patterns associated with oboe playing, posture during playing, and physical properties of reeds suiting beginners. The explanation for the discrepancies among the views of these authors, excellent players themselves, is that verified information is not available on all physiological parameters of oboe playing.

1.1 Circulatory and respiratory effects of oboe playing

Oboe playing is a very specific physiological stress. Rothwell (1974) described dizziness as the oboist's symptom caused by diminished circulation. Circulatory effects result from the high airway pressure which is necessary for the sound production in oboe playing. Exceptionally high mouth pressures have been recorded during wind playing (Roos 1936; Benade & Gans 1968; Bouhuys 1968).

The respiratory rhythm is profoundly changed during wind playing. The length of musical phrases dictates the duration of expiration. Inspiration is possible only during the short intervals between phrases. The breathing pauses are often very short, but the phrases may last even 30 seconds. Because of the exceptional breathing pattern, Tolksdorf and Rösler (1978) suggested that "necessary precondition for oboe playing are healthy lungs and heart as well as excellent functioning of respiratory muscles".

According to basic respiratory and circulatory physiology (see eg. Mountcastle 1980, West 1983), the blood flow in pulmonary capillaries is very sensitive to pressure changes in airways. An alveolar pressure of about 2.5 kPa above the atmospheric has a marked effect on pulmonary circulation. The airway pressures measured during oboe playing exceed this value (Benade & Gans 1968; Bouhuys 1968). Prolonged maintenance of a high airway pressure disturbs pulmonary circulation. Arterial blood pressure decreases in systemic circulation. When the systolic pressure falls, autonomic nervous reflexes increase the heart rate and the diameter of the resistance vessels decreases to restore the circulatory steady state.

Respiration is under the control of chemoreceptors which are sensitive to the carbon dioxide concentration of blood, and proprioceptors which react to the expansion of the chest cavity during the respiratory cycle. If ventilation is adequate, no stimuli are sent from chemoreceptors to the brain during a long expiratory phase, because the carbon dioxide concentration does not change markedly. However, pulmonary stretch receptors become activated when expiration is prolonged. The phenomenon is called the Hering-Breuer reflex and it plays a significant role in adults only when the tidal volume exceeds one litre (Guz, Noble et al. 1970).

The main role of proprioceptors is to send messages of the expansion of the thoracic cavity during inspiration to the respiratory centre and to stop the inspiratory effort. If expiration starts within the limits of the normal tidal volume, there is no known proprioceptor reflex to stop inspiration in adults. However, after high inspiratory volumes expiration is hurried up by the Hering-Breuer reflex. Relaxation of inspiratory musculature, caused by the reflex, has to be prevented voluntarily, if the slow outflow associated with wind playing is to be maintained. The prevention is possible only by means of constant motor output from the cortex to the respiratory muscles (Cohen 1970). Therefore, long phrases cannot be played without balancing these models of respiratory control.

1.2 Acoustic properties of the oboe and the need of pressure during playing

The oboe is a woodwind instrument with a sound generator made of two pieces of cane tied together. Sound production takes place when the player blows a pulse of positive pressure into the instrument through the reed. The energy of the air puff gives the reed an impulse to move. Energy is also needed to carry pressure waves to swing forth and back between the ends of the pipe. It is also released as several kinds of energy losses - viscous, thermal and turbulent - in the player's mouth, the reed system, the main air column, and in the finger holes (Benade & Gans 1968).

There are remarkable differences in bore, materials and inside surface finish among different winds, and even among instruments of the same type. Therefore, the need of energy in sound production differs depending on the qualities of the instrument in question. In those parts of the instrument where the flow is highest, the energy losses are greatest.

Because of the narrow reed system of the oboe, the air puffs during playing are small, and consequently the air flow through the instrument is also small. Since the flow is small in the main air column inside the pipe, the turbulent, thermal and viscous losses are small. Thus, the high pressure is retained inside the reed. Consequently, the energy is primarily lost in the reed system itself, and the amount of energy loss depends on the qualities of the reed, especially on its shape and surface finish.

Great individual differences in blowing pressures have been measured among oboists in earlier studies. In 1878, Stone (cf. Roos 1936) measured pressures between 2.25 and 4.25 kPa. Almost a hundred years later, Bouhuys (1968) obtained values that varied from 3.8 to 10.4 kPa. The interindividual differences in blowing pressures during oboe playing are probably caused by differences among the reeds and by the manner players use them. For pedagogical purposes, it is important to know how the need and consumption of energy are affected by the qualities of the reed and by the playing technique.

1.3 Music education in Finland

Music education is well organized in Finland. Music is taught to all children at kindergarten and at school. For more-than-average musically talented children there are pre-instrumental "music play schools" for infants and music schools for school-aged children (Palonen 1993). These schools are not part of the obligatory educational programme but are supplementary services supported by community. Children attend music lessons after ordinary school hours, usually in one to three evenings a week.

The curriculum of the national music education is issued for music schools by the Ministry of Education. The curriculum standardises the examinations and the subjects studied which include solo instrument playing or singing, music theory, history, choirs, chamber music, and orchestra playing (Palonen 1993).

The qualification requirements of the teachers in music schools have been legislated since 1969 (Palonen 1993). The teacher training curriculums consist of studies aiming at high soloistic skills, good knowledge in music theory and history, and pedagogical and psychological skills. The physiology of playing and singing is not a subject in teacher training. Instrumental tutors are thus music teachers' key source of information about the physiology associated with playing. Therefore, teachers must rely on pedagogical literature when they act as coaches for their pupils or orchestras. Unfortunately, some instrumental books offer no information on this subject, and the information found, for instance, in oboe tutors is conflicting (Table 1).

TABLE 1 The information offered in oboe schools. The oboe schools were analysed according to the existence of literal information about physiology of playing and instructions for practice.

The title of the oboe school	Elementary book	Progressive collection of studies	Physiological information	Instructions for practising
1 Barret: Méthode complete de hautbois 1-3	*	*		*
2 Brod: Études et sonates pour hautbois 1-2		*		
3 Davies & Harris: 80 graded studies for oboe		*		
4 Debondue: Vingt-cinq études - déchiffrages		*		
5 Ferling: 48 études op. 31		*		
6 Flemming: 60 Übungstücke für Oboe		*		
7 Giampieri: 16 studi giornalieri di perfezionam.		*		
8 Gillet: Études pour l'enseignement superieur		*		
9 Giot: L'ABC du jeune hautboïste 1-2	*	*	*	*
10 Hinke: Elementarschule für Oboe	*	*		
11 Hovey: Elementary Method	*			
12 Kubát: 50 études in Phrasing	*			
13 Lacour: 50 études faciles et progressives	*	*		
14 Lamorlette: Douze études pour le hautbois		*		
15 Lamotte: Dix-huit études pour hautbois ou sax.		*		
16 Langey: Practical tutor for the oboe and the c.a.	*	*	*	*
17 Loyon: 32 études pour hautbois ou saxophone		*		
18 Luft: Etüden für 2 Oboen		*		
19 Mille: Zwanzig Studien für Oboe		*		
20 Prestini: Raccolta di studi per oboe		*		
21 Rothwell: The Oboist's Companion	*	*	*	*
22 Rösler: Oboe-Studies I-II	*	*	*	*

The title of the oboe school	Elementary book	Progressive collection of studies	Physiological information	Instructions for practising
23 Salviani: Studi per oboe		*		
24 Sellner: Méthode pour hautbois ou sax. 1-2	*	*		*
25 Socewicz: Scales, arpeggios and intervals	*			
26 Socewicz: Major and minor scales in intervals	*			
27 Śnieckowski: Scales for the French Oboe	*			
28 Śnieckowski: Wybór etiud na obój 1-3.		*		
29 Szeszler: Oboaiskola 1-2	*	*		
30 Tolksdorf & Rösler: Schule für Oboe I-II	*		*	*
31 Voxman: Selected studies for oboe		*		
32 Voxman: Rubank advanced method for oboe		*		
33 Wastall: Learn as you play oboe	*		*	*
34 Wiedemann: 45 Etüden für Oboe		*		

Increased reliable physiological knowledge helps teachers to use valid information for teaching ergonomic breathing technique, motor control and intonation. Therefore, this investigation concentrated on the essential aspect of the physiology of wind-instrument playing, i.e. breathing and its consequences. The methods for investigation were chosen according to the nature of the study: The aim was to find out physiological phenomena, not the statistics of their existence.

2 LITERATURE REVIEW

2.1 Two opposite opinions about the importance of physiological knowledge

Contrasting opinions about the importance of physiological knowledge as an aid for teaching can be found in wind-pedagogical literature. Opposite points of view have been introduced by wind players Johnson (1986) and Rothwell (1968). Johnson considers discussion on physiological parameters a mere waste of time, because he thinks that occupational health problems are as rare among musicians as some tropical diseases. Rothwell, on the other hand, considers this kind of knowledge to be most valuable for pedagogical work.

Keith Johnson admits that it is fascinating to study neurology and physiology. However, he insists that there is no use of such knowledge in understanding learning or performance. On the other hand, he says that all aspects of trumpet playing correlate with breathing, and that the embouchure dictates the quality of timbre and the exactness of intonation. Also, he confesses that the training of physical skills takes a great deal of a player's daily practice hours. However, problems with endurance are symptoms of stage fright. If a player has not enough playing endurance during his daily training, it means, according to Johnson, that he suffers from stage fright during practise, too.

Evelyn Rothwell, a famous oboe teacher from Britain, has described oboe playing as a kind of stress which may cause dizziness because of diminished venous return, but, when practised correctly, may strengthen pulmonary functioning.

The importance of studying the work physiology of musicians has always been underestimated. Because of the demanding spiritual, intellectual and emotional character of musicianship, the physical effort, inherent in musical work, is easily forgotten. The fact is that wind-instrument playing often makes the musician work under extreme physiological conditions.

Both the high expenditure of air and high airway pressure may cause dizziness during playing. The reasons for this are hyperventilation and certain circulatory changes (Faulkner and Sharpey-Schafer 1959). These typically rapid physiological changes which occur during playing may have disastrous consequences on the musical performance. Dizziness is a rather common symptom among beginners but is less frequently experienced by professional wind instrumentalists (Rothwell 1968). This means that the professionals, perhaps, have somehow learned to play more economically.

Both the ergonomy and physical performance of playing can be explained in physiological terms. The first aim of the present study was to find out which matters Finnish wind teachers considered important, what kind of physiological knowledge they had about playing, how they had gained the information, and what their general attitude towards these physiological matters was. The results obtained gave the guidelines for the experimental investigation of this work.

2.2 Breathing

2.2.1 Normal breathing

According to basic respiratory physiology, inspiration is always an active process (eg. West 1983). The diaphragm contracts and descends, and the lower outer intercostal muscles contract to widen the rib cage. When the volume of the chest increases, the airway pressure with respect to atmospheric pressure falls below zero and air begins to flow into the lungs.

In expiration, after relaxation of the inspiratory muscles, and without any active muscular work due to the elastic properties of the lungs and chest, the volume of the chest decreases, the pressure in the lungs rises to above zero, and air flows out of the lungs. The airway pressure during quiet breathing is between -0.2 and +0.5 kPa, depending on the phase of the cycle.

During quiet breathing there are 12-18 breathing cycles per minute. As a result of physical effort the frequency of respiration increases. Both phases of the cycle become more active and the auxiliary breathing musculature is called into action. The tidal volume increases and the maximum airway pressure during relaxed expiration increases even up to +3.0 kPa. During expiratory muscular activity the airway pressure sometimes increases even more. During coughing it may reach 10.0 kPa.

2.2.2 Respiratory changes associated with wind-instrument playing

Breathing patterns are far from normal during wind-instrument playing (Benade & Gans 1968). Lung volumes are completely different from those during quiet breathing (Roos 1936). Airway pressure is either too high or too low in relation to lung volumes during spontaneous breathing (Roos 1936; Bouhuys 1964).

Inspiration is extremely rapid, but the duration and effort of expiration vary extremely.

During a musical performance, the expiratory phase may last nearly half a minute. An extremely high airway pressure is needed for playing wind instruments such as the oboe and high brasses (Benade & Gans 1968). The expenditure of air is very small, especially in the playing of the oboe (Weisberg 1975).

There is a great variation in the expenditure of air among the instruments (Roos 1936). Therefore, discussion about adequate inspiration arises every now and then among musicians. Opinions on the depth of preparatory inspiration vary (Bate 1975; Weisberg 1975). This question has also interested physiologists (Roos 1936; Bouhuys 1964). The other issue concerns the location of breathing: which should widen more, the apex or the base during a musician's preparatory inspiration.

The second aim of this study was to investigate some aspects of the breathing associated with playing different wind instruments: expenditure of air, blowing pressure, lung volumes at the beginning of playing, and the location of breathing.

2.3 Muscular control of breathing

2.3.1 Muscular activity during normal breathing

During normal breathing at rest, one inspires using the diaphragm and the external intercostal muscles to widen the thoracic cavity. Expiration is passive, especially in extreme conditions of rest, such as sleep. The inspiratory muscles relax and the air flows out. During physical effort, both inspiration and expiration become deeper: the auxiliary breathing musculature is brought into action.

2.3.2 Muscular activity during wind-instrument playing

The most complicated motor performance in wind-instrument playing is the use of the breathing musculature. Normal, automatic breathing has to be changed to follow the rhythm of musical phrasing and articulation under voluntary control.

The activity of the wind-instrument player's breathing musculature has been studied by EMG recordings (Berger 1968; Bouhuys 1964; Gärtner 1981). The subjects have been amateurs and the experimental groups small. It is difficult to compare the results of the EMG studies because the electrodes have been placed in different locations. The only extensive EMG study of professional wind-instrumentalists' muscular work is Gärtner's "Investigation of Flautists' Vibrato"(1981). The main aim of Gärtner's work was to discover the model of vibrato playing, but his study also provided a lot of information about flautists' muscular work in sound production in general. His study differed from the earlier EMG recordings mainly with respect to the placement of the electrodes. He also measured the activity of the oblique muscles and found that during playing they were the most active muscles.

Though the main mechanism of sound production is very similar for all wind instruments, there are possibly some differences too. The pressure in flute playing is clearly lower than, for instance, in oboe playing (Roos 1936). Both the air flow and pressure are higher in brass playing than in flute playing. Therefore, on the basis of Gärtner's study, it is not possible to make any definite estimations of the muscular work involved in playing winds other than the floatel winds of the symphony orchestra were not represented in the earlier studies. Neither had singers been included as a comparison group.

Therefore, the third aim of this investigation was to study with EMG-recordings the muscular work associated with voluntary controlled pressure blowing in two groups of subjects: one consisting only of experienced professional "pressure blowers", symphony winds and singers, and the other group of subjects with no experience of wind playing or studies in singing.

2.4 Controlling intonation in wind-instrument playing

To produce a note in tune, string players have to choose the right string , place their fingers correctly on the fingerboard and keep the bow moving on it. In addition to correct fingering or slide position, wind players must control their embouchure and blowing pressure in order to play a given note in tune. The pressure must be produced in the blower's airways by the muscles which usually deal with one's breathing. Maintaining pitch demands a lot of attention and concentration while keeping the embouchure steady and the air-flow continuous (Beanade and Gans 1968; Rossing 1983). No visual help, like a fingerboard or keyboard , is available for controlling the pitch.

The human ear is not perfect regarding the sensation of pitch. There are marked differences among individuals. Highly trained professional musicians have achieved an accuracy of 0.4 cents (1 cent = one hundredth of a semitone) in tests which have been carried out in ideal circumstances. In other tests professionals have reached an accuracy of at least 7 cents, while in the normal population the average accuracy is 21 cents (cf. Rakowski 1968). The human ear also tends to remember the pitch, after a short delay, slightly sharper than it was originally. The degree of this phenomenon, which is always present, depends on pitch-discrimination ability (Rakowski 1971;1972).

Orchestral wind players are some times accused of destroying the intonation in concerts. If wind players really had poor pitch-discrimination ability, they would be able to make only rough corrections in their intonation and gradually slide sharper. Therefore, the fourth aim of this study was to determine with objective methods changes in intonation and airway pressure during wind-instrument playing.

2.5 Oboe reed as an example of unexpected factors in wind-instrument playing

2.5.1 What is "good"?

Oboe teachers have very strong opinions about the material of good reeds; they prefer natural cane to artificial materials. They generally agree that the reeds for beginners should be light to blow, with best possible intonation in each register (Kaarlo Pietikäinen and Asser Sipilä, personal communications).

However, "light" is not an absolute expression. In fact the teachers are saying: "The reed should be as light as possible when made with my method and yielding the acoustic properties I expect". Great differences do exist, in this respect, among reed-making schools in different countries. The most obvious difference is apparent without measurements: European reeds have normally a shorter scrape than American reeds, and the scrape is either U- or V-shaped in Europe while in America it is usually like a W.

2.5.2 Ledet's geographical classification of oboe reeds

David Ledet (1981) has carried out, on the basis of exact measurements, a detailed classification of a large number of solo oboists' reeds used in different countries. French, American, English, Dutch, and Viennese oboists have their typical reed-making traditions. Others make their reeds either as mere copies of these, or have made a synthesis of several types, according to Ledet. He regards German reeds as belonging to some kind of "border-line" type, almost as having a "style of their own".

According to many oboists (cf. Joppig 1981), European reeds can be classified into three main types: German, French, and Viennese. This classification is based on the distict tone qualities of the above reeds: the German reed sounds strong and broad, the French bright and somewhat nasal, and the Viennese light and flexible. The comparison of individual reeds on the basis of this classification is difficult because the tone qualities are rather descriptive and not easily measured.

Ledet based his classification on the measures of the cane, on the length and shape of the scrape and the opening of the tip. He also measured the staple - its total length, and the shape of the narrow end (Figure 1).

The French tradition has had a great influence on reed-making throughout the years, especially in the late nineteenth century when the modern model of the oboe was designed in France by the Triebert family (Bate 1954). The total length of the reed is about 72 mm. The length of the scrape varies between 9 and 13 mm. American reeds were modified from French reeds by Tabuteau (Kaplan and Greiner 1984). The scrape is longer than in the French prototype, 14 - 22 mm. The total length must be shorter in order to maintain the pitch. The heart is an important feature in the scrape area (Figure 1). English reeds usually have a

a = total length of the reed
b = length of the scrape
c = length of the tube
d = diameter of the tip opening
e = shape of the tube opening
f = thick heart behind the tip
U, V, W = types of scrapes

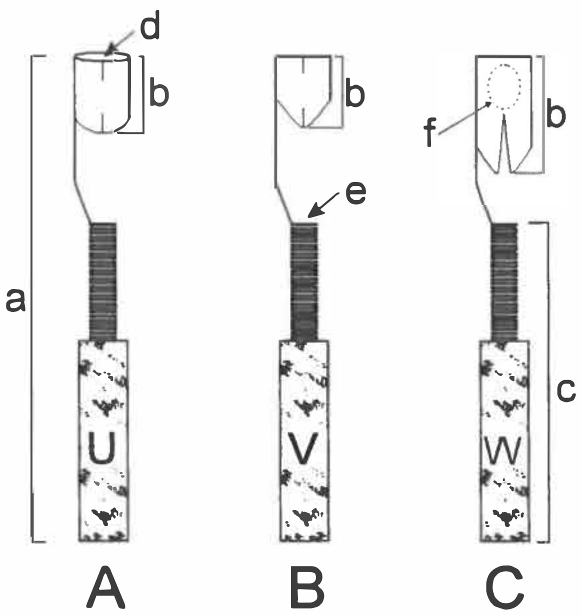


FIGURE 1 Illustration of three types of oboe reeds with some critical dimensions measured in this investigation.

shorter scrape, about 9 mm, and a thinner lay than French reeds. Dutch reeds are thick and broad, 7.05 - 8.00 mm; the length of the scrape with a long tip is 12 - 16 mm. The whole reed is short. The old Viennese-style oboes are still used in the Vienna Philharmonic Orchestra. These have a larger bore than modern oboes, and therefore there are marked differences between the reeds used in these oboes and the ones generally used nowadays. The staple is short, 37 - 38 mm. Its narrow end is round, not oval as in typical modern reeds. The length of the scrape is about 15 - 16 mm. German reeds, which Ledet calls "border-line reeds", could also be called "mean-type reeds" though they are narrower than the others usually are.

Though the shape of the trunk of the oboe dictates the general features of the distribution of overtones, the fine tuning of the timbre is an essential part of reed making. Therefore teachers, when trying to get their pupils to develop a mature sound, are eager to scrape their pupils' reeds using their own reeds as a model.

It can be inferred, on the basis of earlier investigations (Benade & Gans 1968), that the physical properties of natural reeds cause a great energy loss in oboe playing. From artificial materials it is perhaps possible to make more ergonomic reeds for beginners. However, it is almost impossible to scrape them with ordinary reed making tools. Perhaps for this reason teachers are not very fond of them, even when they work with very young pupils.

Because light reeds with good intonation is the goal of reed making for beginners , the fifth aim of this investigation was to study with objective electromechanical methods the intonation and blowing-pressure demands of reeds made of natural and artificial cane.

2.6 Hypothetical adaptive changes caused by wind-instrument playing

After regular training, some physiological changes tend to become permanent. Therefore athletes, for instance, are better prepared to endure physical stress than those who do not train in sports. This is called adaptation. The same may apply to wind-instrument playing, too.

The wind musician works in very exceptional conditions. The minute ventilation and blowing pressure often increase (Roos 1936; Bouhuys 1964; Benade and Gans 1968) so high that without any adaptive respiratory and circulatory changes the consequences of hyperventilation and the Valsalva effect on circulation cannot be avoided.

The nature of the wind instrumentalist's adaptation is as yet unknown. Is it something that is achieved by voluntary breathing technique or is it something that originates from changed circulatory and respiratory reflexes of the autonomic nervous system. Therefore, the sixth aim of this investigation was to find out whether there were any differences between professional wind players' and normal subjects' breathing patterns and circulatory reactions under the simulated conditions of wind-instrument playing. Because a small group of healthy old wind instrumentalists were available as experimental subjects there reactions were compared with age related normal values.

2.7 Occupational health problems in musicians

The first hypothetical harmful influence of wind-instrument playing was reported by W. H. Stone in 1874. He claimed that wind instrumentalists had a greater-than-average risk of suffering from lung emphysema. This hypothesis was disproved by M. Navratil and K.Rejsek as late as in 1968. Many other occupational problems related to wind-instrument playing have later been reported (cf. Teirilä & Salorinne 1990).

The most common complaints among orchestral players are various postural and "overuse" symptoms (Fry 1986). Wind instrumentalists suffer from pain in the upper extremities and back. The oboe and bassoon players' symptom, caused by reed making, was called the "reed-maker's elbow" by Dawson (1986). Slight limitation of movements has also been reported to take place even before any occupational diseases have been diagnosed (Lederman 1986a; Lederman 1986b; Mandel et al 1986).

Flautists suffer from eczema caused by the mouthpiece chafing their chins (Dahl 1978). The symptom has a close relationship with the "fiddler's neck". The mouthpiece can cause pressure that is harmful to the player's occlusion but, on the other hand, congenital dental malfunctions can also have harmful effects on the player's embouchure (Porter 1967; Jago 1978).

For sound production, each wind instrument has its typical airflow and pressure requirements. The airflow during playing may be much greater than during normal breathing , or it may be almost nil while the airway pressure is extremely high (Roos 1936; Benade and Gans 1968; Bouhuys 1968). These changes have been described to result in a collapse of the soft palate (Weber and Chase 1970), and in hernias and haemorrhoids (Fry 1986).

Changes in the pulmonary epithelium of singers and wind-instrument players were reported by Plamenac and Nikulin in 1960. Tachycardia and ECG changes have also been reported (Nizet, Borgia and Horvath 1976). Hearing loss is an occupational symptom which can bother musician's everyday living (Hart et al 1987).

Because occupational health problems among musicians are so common and varying, and since every instrumental group is exposed both to physical and mental stress, the seventh aim of this investigation was to study whether there were any differences in the stress experienced and the symptoms suffered among wind instrumentalists and other orchestra players.

3 THE AIMS OF THE STUDY

The aims of this study were:

3.1 To study Finnish wind-instrument teachers' opinions about the importance of physiological knowledge for pedagogy;

3.2 To find out the relevant features of the breathing patterns during wind playing;

3.3 To compare the muscular activity and its location during playing, singing, and some expulsive events;

3.4 To investigate intonation problems as an example of failures caused by physiological stress during playing;

3.5 To compare oboe reeds made from natural and artificial cane with respect to their quality of intonation and the pressure strain caused by them;

3.6 To investigate if there is some kind of physiological adaptation to wind-instrument playing, and

3.7 To compare the subjective experience of the health hazards resulting from playing winds and other orchestral instruments.

4 METHODS AND SUBJECTS IN INVESTIGATIONS

4.1 The role of physiological knowledge in Finnish wind-instrument teaching

Interviewing was the method to study Finnish wind-instrument teachers' thoughts and opinions about the role of physiological knowledge in wind pedagogy. The interviewees were elementary grade teachers in Helsinki and conservatory teachers in various parts of the country, as well as teachers at the Sibelius Academy. The teachers were contacted by phone or by giving them a preliminary questionary at the Academy. Those who had answered the questionary were also contacted personally. Three of the fifty-four teachers contacted by phone refused to answer the questions. They were either not interested in the matter or did not like to part with their knowledge without any personal profit for themselves.

All participants (N = 51) were teachers of wind instrument playing. They worked either at a music institute or at the Sibelius Academy. They were classified according to their ages: teachers under 25 years of age working at a music institute (n = 12); teachers between 26 and 40 years of age teaching either at a music institute or at the Academy (n = 23); and those who were over 40 years of age and taught students studying for professional degrees at the Academy or at a conservatory (n = 16). See Table 2. The questions - concerning teachers' opinions about the importance of physiological knowledge in teaching, their personal interest in this type of information, and the quality of their knowledge in this kind of things - and the analyses of the answers are shown in Table 4 in "Results". The alternatives of location of breathing were given in a schematic drawing (Figure 2).

One of the teachers duties' is to be a member of examination boards. Thus it is important also to know the difficulties associated with the winds other than one's own instrument. The teachers' opinions about the difficulties related to

TABLE 2 Interviewees of this investigation tabulated according to age, sex and instrument.

Age and sex / Instrument	<26		26 - 40		>40		All		Total
	M	F	M	F	M	F	M	F	
Flute	-	4	-	6	2	-	2	10	12
Oboe	2	3	6	2	6	-	14	5	19
Clarinet	-	1	1	3	4	-	5	4	9
Bassoon	-	-	-	-	1	-	1	-	1
Saxophone	-	-	1	-	-	-	1	-	1
Horn	-	1	2	-	1	-	3	1	4
Trumpet	-	-	2	-	1	-	3	-	3
Trombone	1	-	-	-	1	-	2	-	2
n in age group	3	9	12	11	16	-	31	20	
Total	12		23		16				51

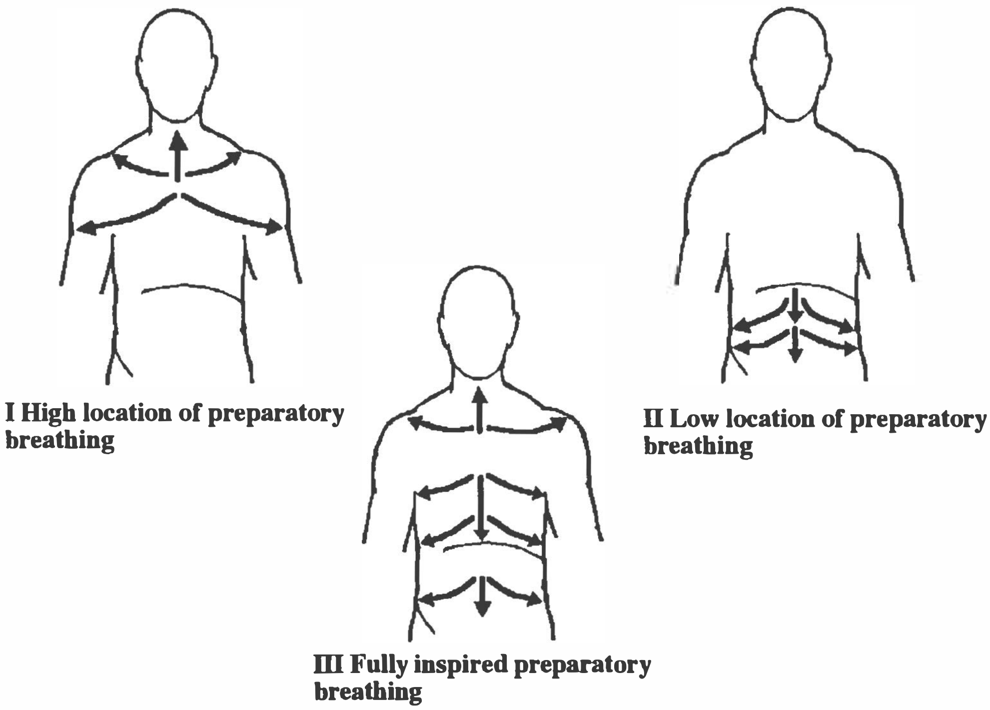


FIGURE 2 The alternatives of breathing patterns offered to the interviewees.

wind-instrument performance were asked. The information was scored on an analog scale from 0 to 5. Five represented maximal difficulty, zero no difficulty at all. The total number of estimators was 24, so that each instrument was represented by three teachers. To avoid preconceived results, the rating reported here was performed by the group who had not answered the questionary. These subjects were the teachers who had not been available for the first questionary. None of them refused to conduct the rating.

4.2 Breathing patterns associated with wind-instrument playing

Sixty-three (63) musicians, professionals of symphony orchestras in Helsinki and students studying wind-instrument playing at the Sibelius Academy, participated as subjects in this study.

Blowing pressure, expenditure of air, and depth of preparatory inspiration were measured in 26 professional wind players: three flautists, two males and one female; eight oboists, four males and four females; four clarinettists, three males and one female; three male bassoon players; one male saxophone player; two male horn players; two male trumpetists; two male trombone players, and one male tuba player.

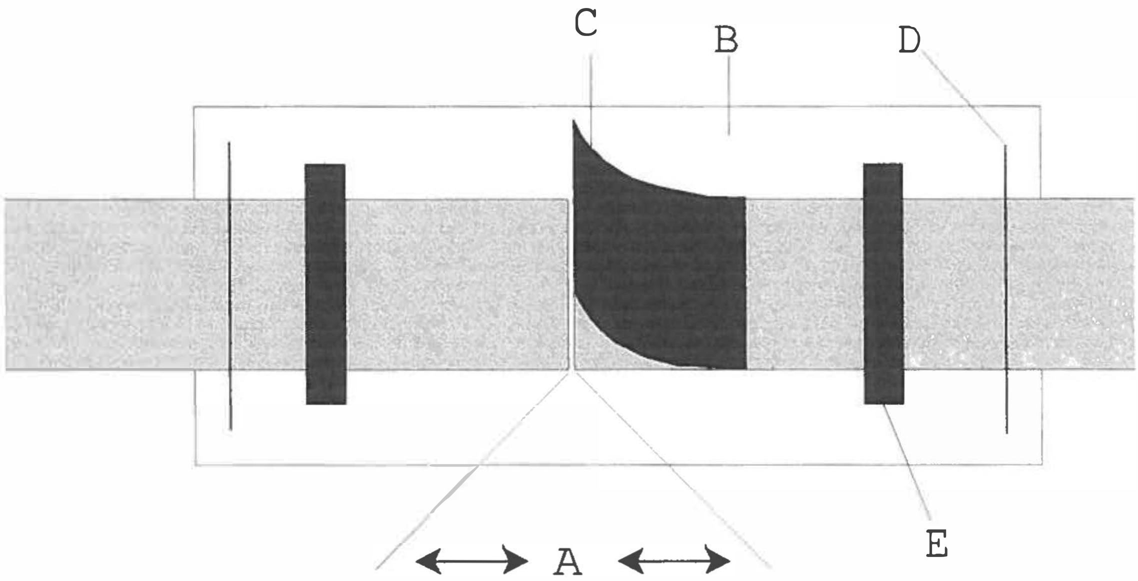


FIGURE 3 Design of the belt measuring chest movements:
A - the ends of ribbon, free to move
B - elastic ribbon (stretching from 10 cm to 18 cm)
C - the piece of stick ribbon with which the belt was closed to the desired respiratory phase
D - seam which connects the firm ribbon with the elastic band
E - supporting loop

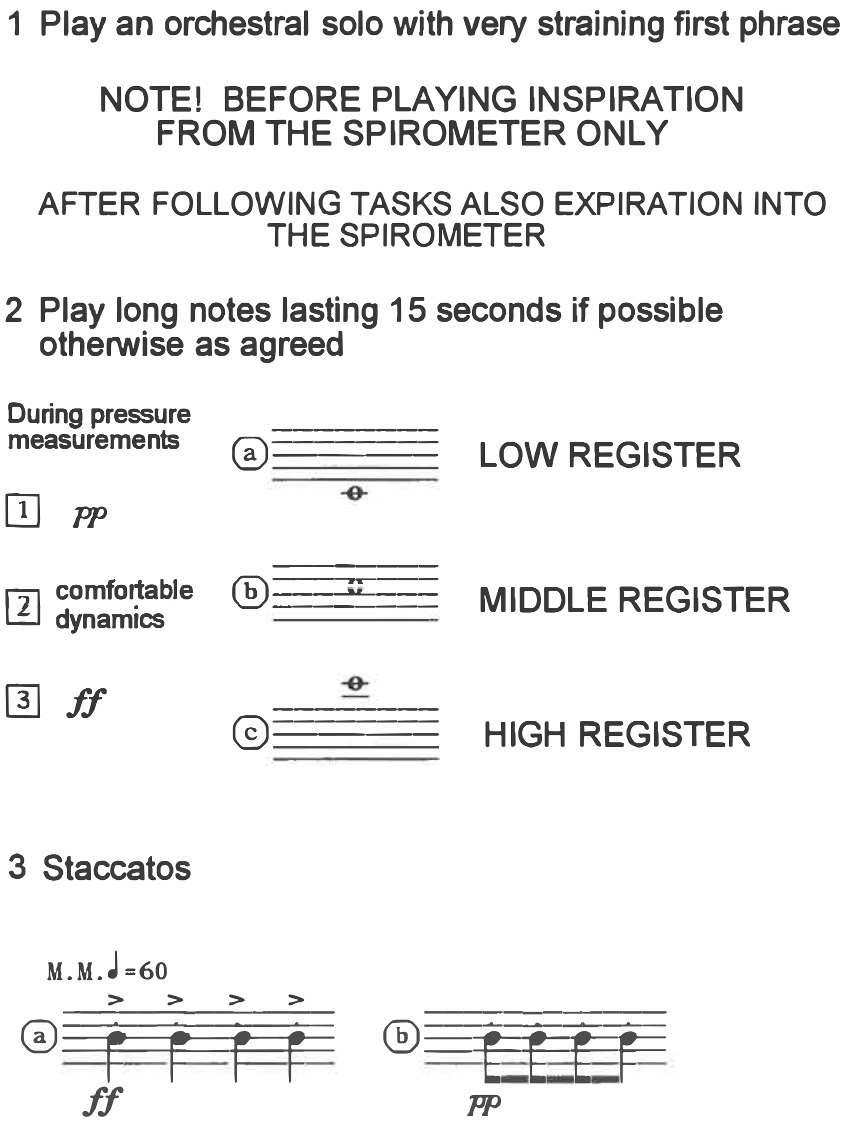


FIGURE 4 Tasks and instructions to the subjects for spirometry and pressure measurements.

Thirty-seven (37) other subjects participated in the tests in which the location of inspiration was determined with belts measuring chest movements (Figure 3). It was necessary to use in this test subjects who had not answered the questionary including a question about the location of breathing. These thirty-five (35) subjects were wind-instrument students at the Academy: nine flute players, one male and eight females; thirteen oboists, six males and seven females; six clarinettists, three males and three females; one male bassoon player; one male saxophone player; two horn players, one male and one female; one male trumpet player; three trombone players, two males and one female; and one male tuba player. Two male oboists were professional orchestral musicians.

To obtain basic information about the breathing patterns that the professionals preferred in different musical tasks (Figure 4), the following parameters were measured:

1. vital capacity;
2. expenditure of air in different musical tasks;
3. blowing pressure in different registers during playing;
4. lung volumes when starting to play a long musical phrase;
5. location of preparatory inspiration before playing.

Vital capacity and the depth of preparatory inspiration were measured with an Ohio flow-volume spirometer. The slow inspiratory vital capacity was measured first. Then the players breathed into the spirometer for a while, inspired to the pre-playing volume and started to play. The nose was closed with a clip and the subject had been told not to breath while changing from the spirometer mouthpiece to the instrument mouthpiece. After playing a preset task (Figure 4), the players expired completely into the spirometer. The expenditure of air during playing was therefore the difference between the volumes of preparatory inspiration before playing and that of expiration after playing.

When a subject felt that changing mouthpieces caused a leakage in breathing the test was rejected. Therefore, for long tones results were gained only from 20 players, and when testing staccatos, only from 15 players.

The airway pressure was measured with a Honeywell Micro Switch PK 8768 0 pressure gauge which was connected to an Elema-Schönander ECG-apparatus for recording. A thin teflon tube was taped on to the corner of the players mouth. The tube was connected to the pressure gauge for blowing-pressure measurements.

The spatial distribution of chest movements was visualized with the belts set around the upper body (Figure 5). One belt was used for observing the upper thorax and the other was placed around the lowest ribs. The stretching of the belts showed the location and direction of the movements of the chest. Breathing patterns were classified into three groups:

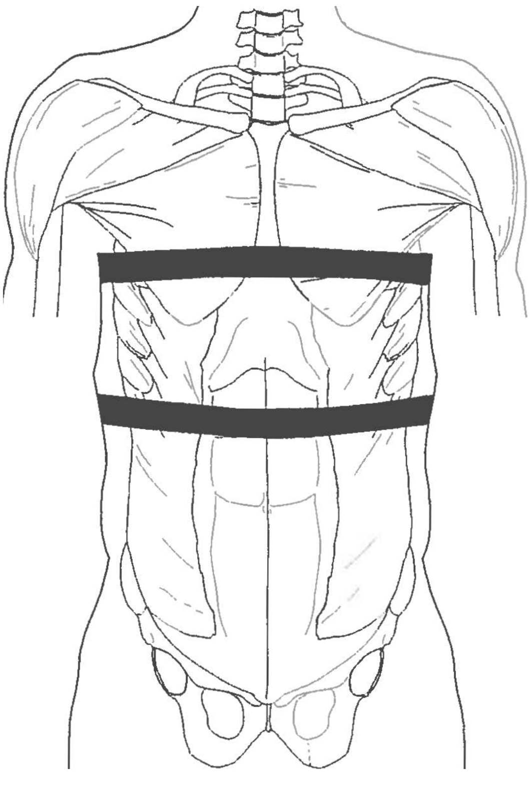


FIGURE 5 Setting the belts: the upper belt was put as high as possible below the armpits, the lower belt over the lowest ribs. During the measurements the belts were closed at the FRC-level.

1. high location = the upper belt stretched more than the lower one;
2. low location = the lower belt stretched more than the upper one;
3. deep inspiration = both belts stretched equally (difference <20%).

The location of inspiration was recorded by photographing the behaviour of the belts during playing.

The experiments were carried out at the Laboratory of Clinical Physiology at Laakso Hospital in Helsinki.

4.3 Muscular activity associated with wind-instrument playing

The subjects in this study were:

1. ten professional wind instrumentalists, aged 18 - 38 years, (four female oboists, the other wind players were all men: one flutist, one oboist, one clarinettist, one bassoonist, one trumpet player, and one trombonist);

2. six professional singers, aged 25 - 36 years (of whom four were opera singers, two males and two females, and two female church musicians); and

3. six control subjects, aged 20 - 31 years (three females and three males) who had not studied singing or wind-instrument playing.

Phases of the study were as follows:

1. the subjects were interviewed in order to choose the locations of the electrodes adequately;

2. recordings were conducted in the three groups of subjects; and

3. the recordings were analysed and conclusions were drawn for pedagogical purposes.

4.3.1 Location of electrodes

The subjects were asked to give their opinion on the location of muscular activity during the playing of different musical tasks. They were asked to show the most active areas on schematic drawings of the human body (Figure 6). All subjects indicated activity in the abdominal and external oblique area. The external oblique area was the location studied in earlier investigations (Berger 1968; Gärtner 1981). In those studies also the trapezial, pectoral and upper abdominal area were recorded. These locations were, however, not chosen by the subjects. In the present investigation these areas were also recorded for comparison with the results of the previous investigations (Figure 6).

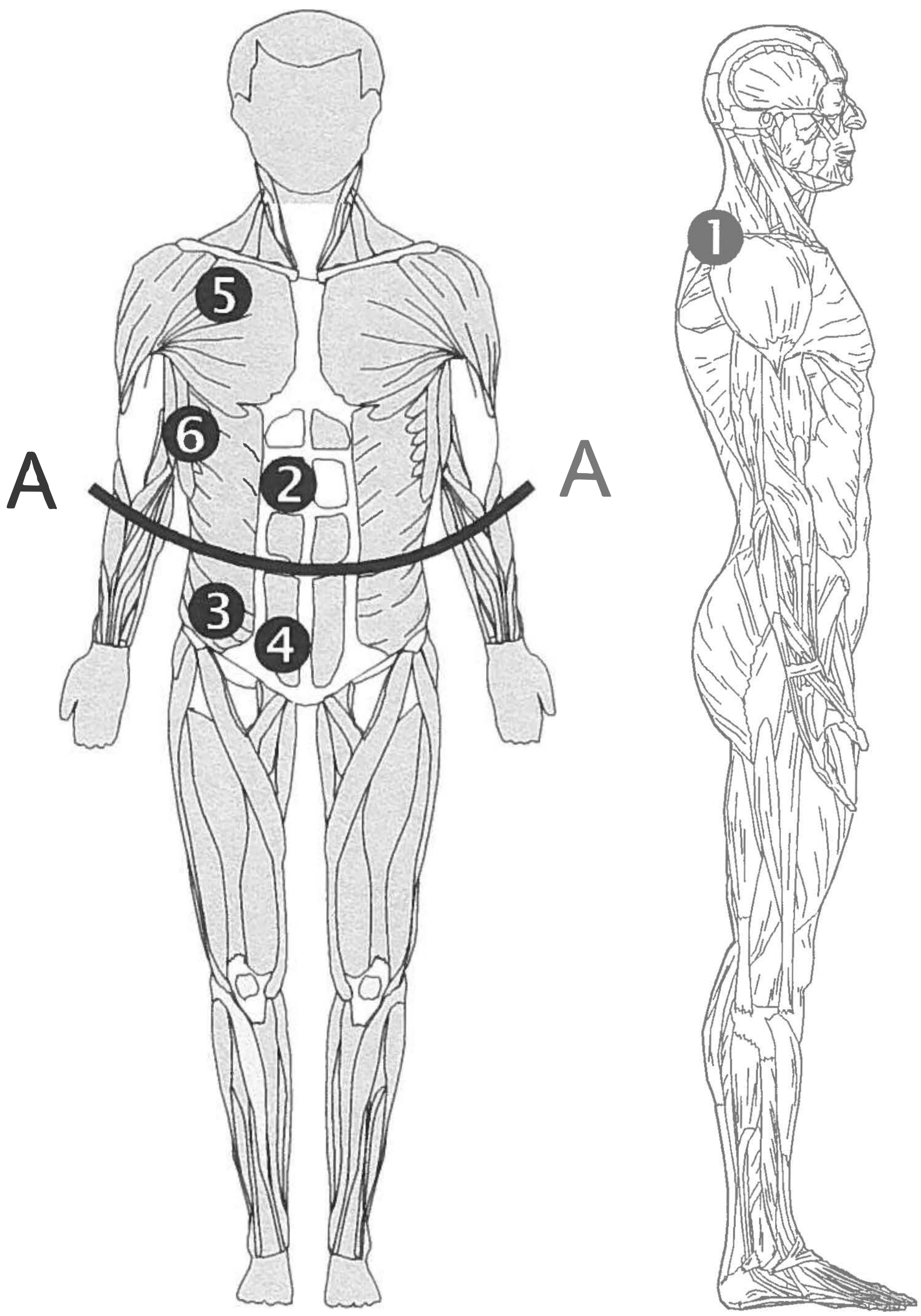


FIGURE 6 Location of electrodes during EMG-recordings:

1. trapezial area; 2. upper part of abdominal muscle; 3. external oblique area; 4. lower abdominal area; 5. pectoral muscle; 6. serratus muscle.

According to the subjects' opinion (introduced before measurements in order to find the adequate recording spots) the most active musculature during wind-instrument playing was beneath line A-A.

FIGURE 7 The tasks and instructions to the subjects participating in the EMG-recordings.

4.3.2 The experimental tasks

A list of tasks (Figure 7) was on a music stand in front of the subjects during the recordings. The tasks were carried out in numerical order. The wind players performed all the musical tasks, the singers tasks 6 and 7, and the non-musicians only task 7.

All non-musicians and seven musicians also performed the pressure blowing tasks. The subjects were taught to control their mouth pressure with a clock barometer (Figure 8). The pressures were 4.0 kPa and 8.5 kPa. The EMG-recordings were made when the subjects blew the given pressure into the barometer, starting the blowing at two different respiratory phases: 1. after inspiration to total lung volume, and 2. after expiration at FRC-level. The recommended duration of the tasks was 7 - 15 seconds, if possible. Care was taken that the glottis was kept open during blowing. At least one minute of rest followed each effort.

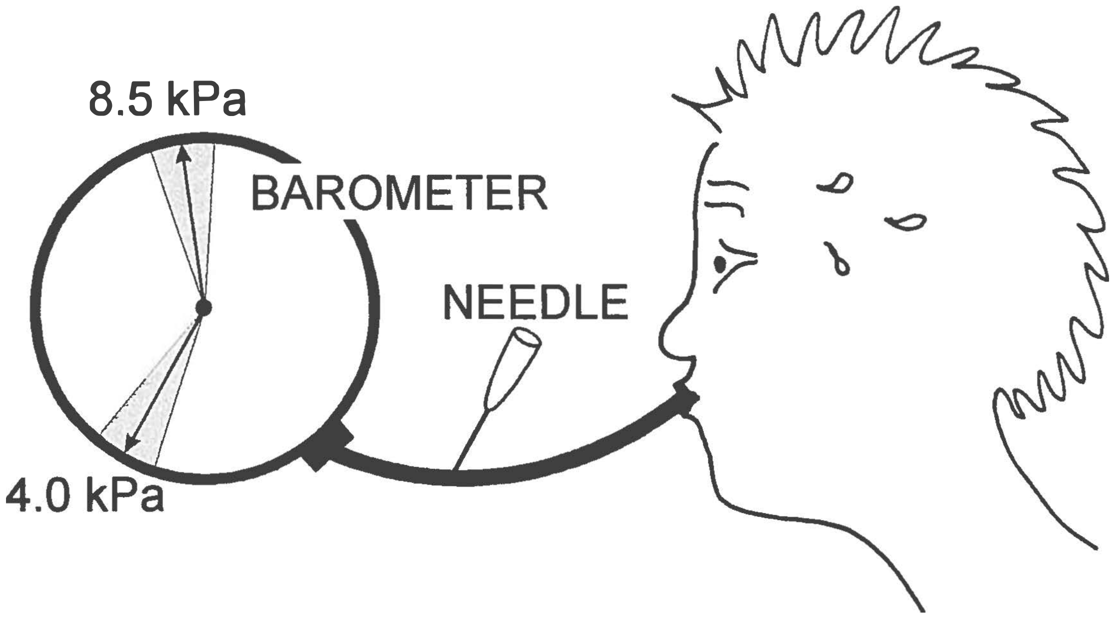


FIGURE 8 The subjects controlled their airway pressure by blowing into a barometer on which the two pressure levels required were marked. A thin needle ensured the airflow by causing a leakage in the tube.

4.3.3 Analysis of EMG activity

The magnitude of EMG responses is affected by the muscle mass, the amount of adipose tissue between the skin and muscle, and the placement of the electrode on the muscle recorded. Because surface electrodes were used, it was possible to record only sum-activation. Therefore five activity levels were estimated for each recorded muscle:

0 = no effort = resting muscles

1 = very low effort = minimal muscular work

2 = definite, continuous, but not very strong effort

3 = strong effort, which can be maintained voluntarily without the limitation of immediate fatigue

4 = very strong effort, not maintainable for more than a couple of seconds without special motivation.

A ruler, on which the activity levels were marked, was constructed for each subject and calibrated for each recorded muscle (Figure 9). It was slid over the recording paper, and the measured muscular activity was marked on the recordings at one-second intervals in long tasks. When sudden changes were observed in activity, the corresponding spots were marked on the recordings. The corresponding phases of each task were analysed and tabulated according to the scale above.

4.3.4 Equipment

The recordings were made with a Siemens EEG recorder, using small Medicotest surface electrodes type N-35-A. The paper speed during recordings was either 10 or 20 mm/s. Pressure was gauged with a Wika 0/300-mbar mechanical barometer.

The experiments were carried out at the Department of Physiology, University of Helsinki.

4.4 Intonation problems in wind-instrument playing

The subjects were 25 professional wind players from symphony orchestras in Helsinki. They were both males and females, aged 20 - 50 years. This group consisted of two flautists, eight oboists four clarinettists, one saxophone player, three bassoon players, two French horn players, two trumpet players, two trombonists, and one tuba player. These subjects participated, also, in breathing pattern measurements (Chapter 4.2).

The tasks to play during the recordings were long notes in three registers, each note lasting 15 seconds, if possible. In each register, three different dynamics were played: pp, "comfortable" = something between mp and mf, and ff. During the tasks, pitch dynamics and mouth pressure were measured simultaneously (Figure 10).

Pitch was gauged by a Korg manual tuning meter. A Honeywell Micro Switch PK 8768 0 pressure meter was used for the mouth-pressure measurements.

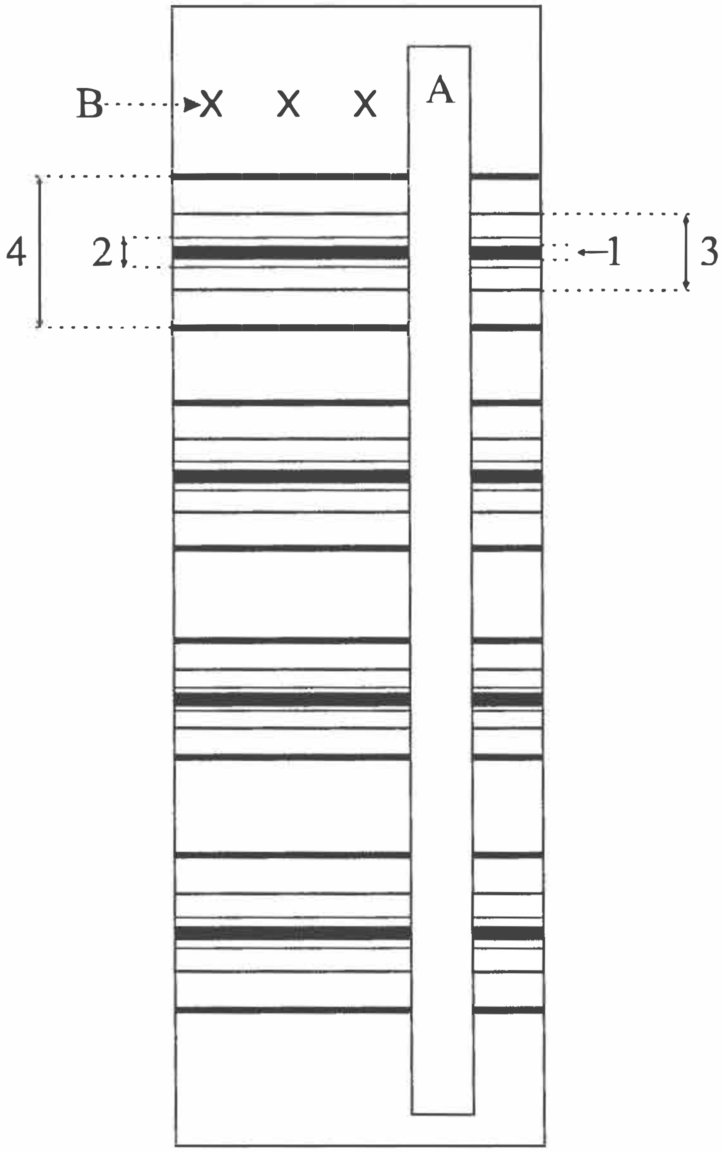


FIGURE 9 The ruler which was constructed from transparent material for reading EMG recordings. Calibration for each muscle (activity levels 0-4) was marked on the ruler. Each subject had a ruler of his or her own. A indicates the window for writing on the recording paper. B is the time scale at one second intervals.

The dynamics were checked with an MIP-7178 dB-meter. All the equipment was connected to an Elema-Schönander ECG-apparatus which was used as a recorder. Pitch was calibrated according to a 50-cent change in the tuning meter before each experiment (Figure 10).

The experimental procedure and the purpose of the study were explained to the subjects. They were asked to indicate immediately when the method bothered them so much that it might affect the results. Each note was practised 1 - 3 times. If saliva plugged the tube, the recordings were rejected. The whole procedure was carried out in all subjects with exception of one trumpetist. All his recordings had to be rejected because of his difficulties to play with the teflon tube.

While playing, the subjects stood in the middle of a square laboratory room, which measured 6 by 6 metres. The bell of the instrument was at a distance of 60 cm from the microphones. A thin teflon tube was taped to the corner of the mouth for the pressure measurements (Figure 10). Before playing a note, the players heard a short tuning sound played with the Korg tuning meter. The players rested for a while between each note. The experiments were carried out at the Laboratory of Clinical Physiology, Laakso Hospital, Helsinki.

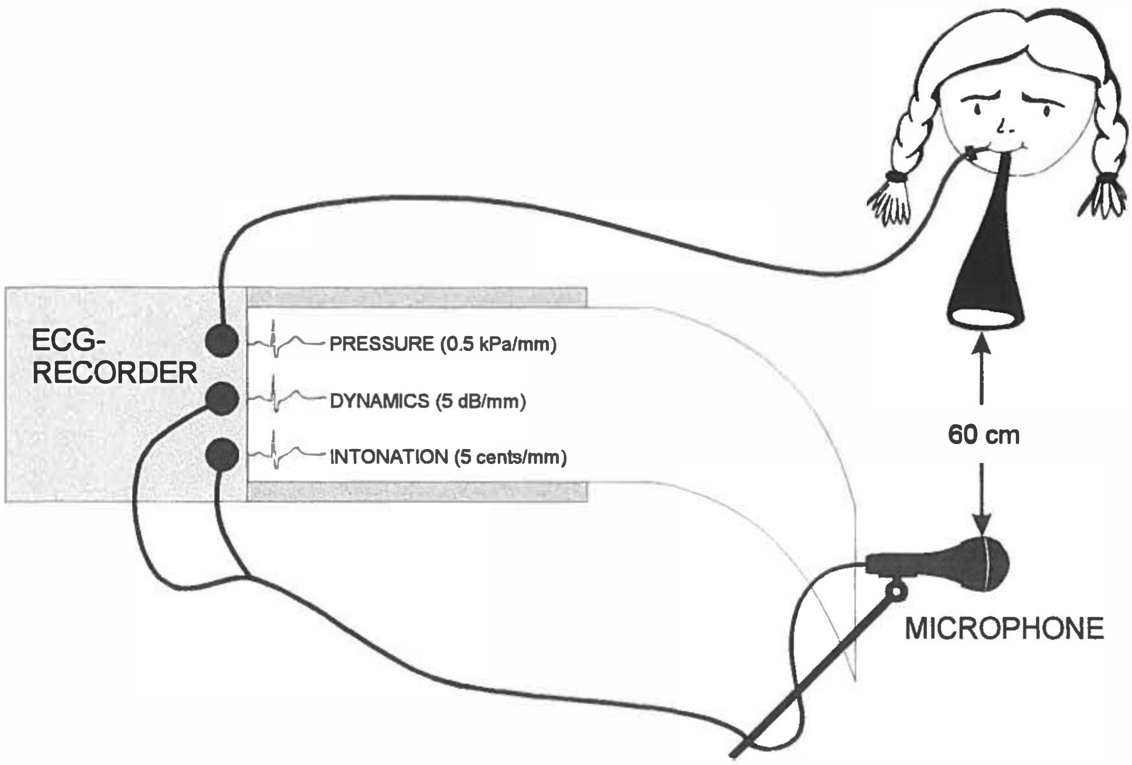


FIGURE 10 Experimental procedure for testing intonation accuracy: subjects played long notes in different registers and dynamics while simultaneous recordings were made of mouth pressure, dynamics and intonation.

4.5 Comparison between oboe reeds made of natural and artificial material

4.5.1 The reeds

Sixteen reeds were measured. Ten of them were professional oboists' normal reeds. Six reeds were made of artificial cane, three of plastic - all supposed to be similar - and three of fibre-glass classified by manufacturer according to stiffness: S = light, M = normal, and H = stiff (hard).

4.5.2 Measurements

Four variables were measured: 1. dimensions of the reeds, 2. pressure needed to make the reed vibrate; 3. failure of intonation (in normal tuning).

4.5.3 Dimensions of the reeds

The dimensions measured in this investigation were: 1. the thickness of the cane, gauged at the spots marked in Figure 11; 2. the length of the scrape, gauged at the

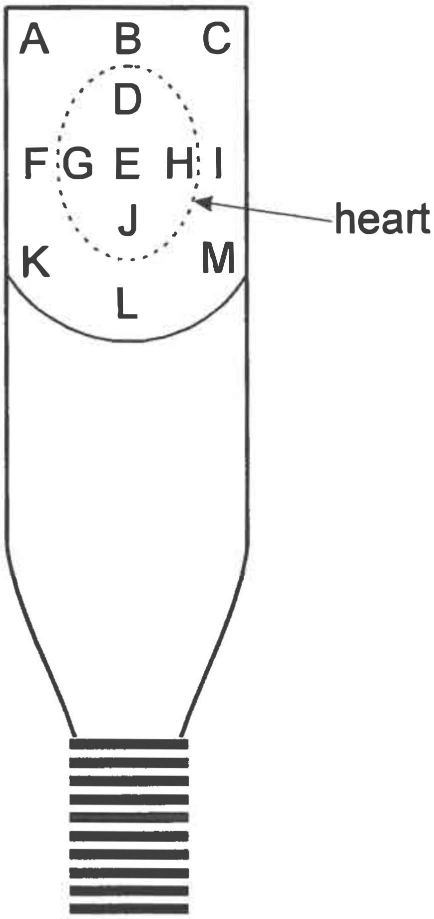


FIGURE 11 Spots (A - M) on the oboe reeds wher the thickness of the cane was measured in this investigation.

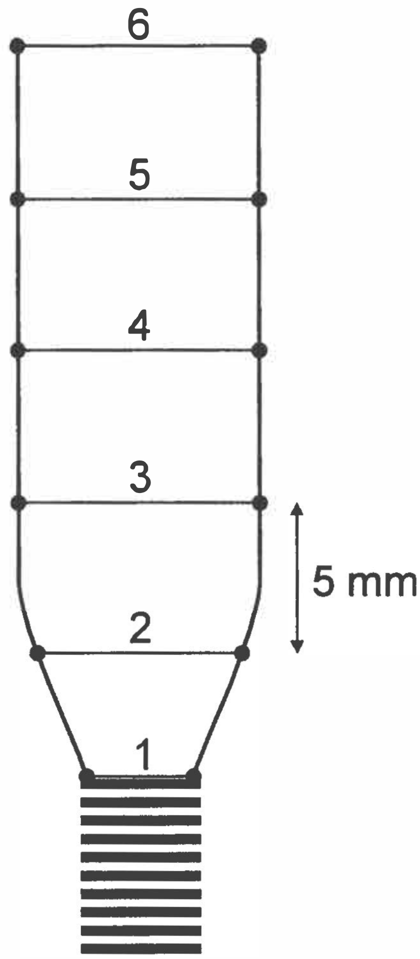


FIGURE 12 The breadth of the cane was measured at 5 mm intervals in the places shown in the figure.

mid-line and both edges of the reed; 3. the length of the vibrating part of the cane; 4. the breadth of the cane, gauged at the spots shown in Figure 12; 5. the tip opening, gauged at the spot shown in Figure 1; and 6. the total length of the reed.

The thickness of the cane was gauged with a Howarth-Mercer reed-gauge. The measurement procedure is shown in Figure 13. The length of the shaft limited the possibilities of reliable measurements.

The lengths and breadths of the reeds were measured with a digital Preisser Digi Met precision gauge.

4.5.4 Blowing pressure and intonation

It is possible to regulate the need of blowing pressure with the contact of the lips with the reed. To get reliable information about the need of pressure, the influence of the lip contact was eliminated. The reed was put into a plastic tube which was connected to the mouthpiece system. The pressure gauge was a Wika mechanical barometer which was also connected to the mouthpiece system. The measurement procedure is seen in Figure 14.

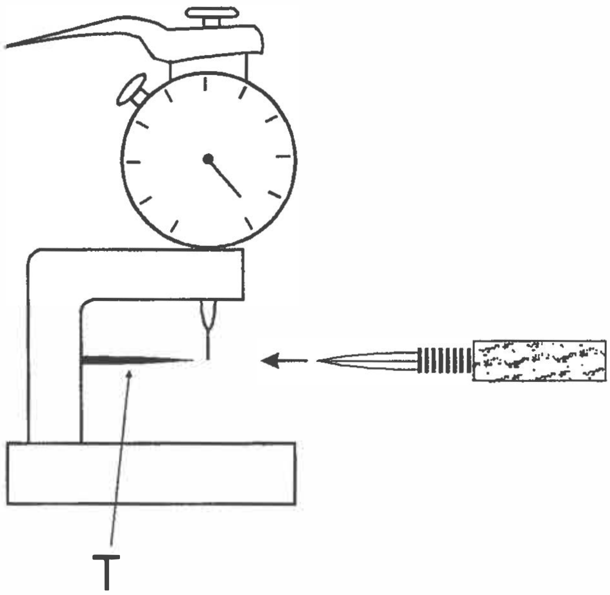


FIGURE 13 Measuring procedure of the thickness ot the reeds. Micrometer, constructed especially for measuring oboe reeds, is completed with a "tongue" (=T). It supports the reed when the scrape area is measured. Reliable values were oblained only in a limited area because the tongue permitted a back-and-forth movement of only about 20 mm without bending the blades outwards.

During the test, a C major triad was played in the lower register. The investigator blew into the mouthpiece until the reed started to vibrate. Because the human lungs were the pressure generator, the humidity of the air blown was normal. The values of the pressure and the intonation failure were written down by an assistant at the onset of each sound.

Intonation was controlled with a Korg auto chromatic tuner AT-12. The instrument played in the tests was a Marigaux oboe (4009). The experiments were carried out at the Department of Physiology, Helsinki University.

The reeds were classified according to Ledet's system based on the dimensions of the cane and scrape.

The factors affecting intonation and blowing pressure were revealed by cross-tabulating the reeds according to intonation and pressure behaviour. For obvious factors correlations were calculated.

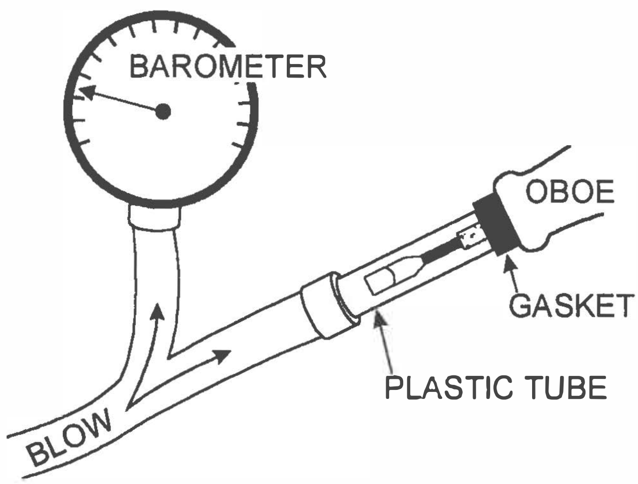


FIGURE 14 Measuring procedure of the pressure demands of reeds without lip control.

4.6 Adaptation associated with wind-instrument playing

The study was carried out on four groups of subjects. Two groups consisted of musicians: 33 wind-instrument students, 20 - 26 years of age, representing both sexes, and 7 experienced professional orchestral wind players, 35 - 76 years of age, who were all males. The two control groups consisted of 32 medical students, 20 - 25 years of age, and 14 beginners, 10 - 43 years, tested before their first wind lesson. Both groups included males and females.

4.6.1 Equipment

The tidal volume was measured with a mechanical Stead-Wells, Warren e. Collins spirometer (tank spirometer) which enabled the measurements in lying position - the recording lasted from 5 to 10 minutes.

The breathing pattern before playing was tested with a computerized Medicro Mikro Mikko spirometer using the time/volume measurement programme.

The beginners' breathing patterns before pressure blowing were visualized with the belts measuring chest movements (Figure 3) and recorded on a video tape.

Autonomic circulatory reflexes were tested by electrocardiography. The R-R intervals were counted using a computerized programme (Tahvanainen 1989). ECG was recorded with an Elema-Schönander four-channel recorder which was connected to an IBM microcomputer. The airway pressure was controlled with a mechanical Wika barometer during the Valsalva tests.

4.6.2 Spirometry

The tidal volume was measured in lying position to keep the subjects as relaxed as possible. The duration of the measurement was from five to ten minutes.

The breathing pattern before playing was recorded in sitting position. The subjects practised the procedure before the experiment by breathing through the spirometer for a while. While waiting for their turn to play a solo, the subjects were instructed to try to find a comfortable position to be able to inspire through the spirometer as naturally as they would normally breath. No breathing was allowed during the change from the spirometer mouthpiece to the instrument mouthpiece. The nose was closed with a clip to prevent unconscious breathing through the nose.

During the experiment, the subjects respired for 30 seconds through the spirometer before playing. Then they played a long note in the middle register with dynamics mp - mf.

A pressure-blowing task with the belts measuring chest movements (Figure 3, Chapter 4.2) was conducted to the wind-instrument aspirants who had never before played an orchestral wind. Observations were made of the changes in the depth of breathing during the last three respiratory cycles before preparatory breathing, and in the depth of the final preparatory inspiration before blowing. Also, the aspirants were asked to sing when wearing the belts. The depth and location of preparatory breathing were observed before singing.

4.6.3 Valsalva tests

During the Valsalva tests, the subjects sat in a resting position in an armchair with a cushion behind their necks. The tests were started after a 2-5-minute period of rest. The first sample of ECG was recorded during rest. The blowing tests started with a half-minute period of rest for control purposes. After this period, the subjects immediately started to blow against the given pressure, checking the pressure themselves by means of the mechanical barometer. To keep the glottis open, a tiny leak was arranged in the tube of the gauge by puncturing it with a needle. The pressure blowing lasted from 15 to 45 seconds depending on the players ability. The test was repeated at three pressure levels: 1.9, 4.5, and 8.0 kPa. The subjects were advised to breath before pressure blowing as they would before an orchestral solo.

The experiments were carried out at the Institute of Physiology, University of Helsinki; at the Laboratory of Clinical Physiology, Laakso Hospital, Helsinki; and at the Sibelius Academy.

Breathing patterns before playing were classified according to the FRC level, respiratory frequency and tidal volume.

The subjects' Valsalva reactions at the normal Valsalva delay or when the test was lasting longer than during normal testing were compared with age-related reference values (Piha 1988) .

4.7 Subjective experience of occupational health problems among wind-instrumentalists and other orchestra players

A questionary (Table 3) was sent to professional orchestral musicians in Helsinki during the 1987 -1988 season. The players were informed about the reasons for the questions. They were told that no individual cases should be published but the results would be reported with respect to different groups of musicians, mainly wind players versus other musicians. The subjects were asked to list the possible occupational and other symptoms they suffered from and tell about their subjective experiences of the reactions they estimated to be normal among musicians.

TABLE 3 Questions to musicians for subjective assessment of their occupational health problems.

QUESTIONARY FOR ORCHESTRAL MUSICIANS		
1	How do you estimate your stage fright as compared with "normal"?	- worse - average - easier
2	How do you estimate your self confidence as compared with "normal"?	- better - average - weaker
3	Describe how stage fright bothers your playing and welfare.	
4	In what kinds is of tasks the possibility of failure prominent?	
5	If you use any medication to get relief for your stage fright, please, name the medicine and tell the dose.	
6	What other means than medication do you use to minimize the problems caused by stage fright?	
7	Do you have any chronical disease or symptom repeatedly?	
8	If you are on medication for them, please, name the medicine and tell the dose.	
9	Name your instrument and your desk in the orchestra.	
10	Please, name your orchestra and tell how long you have played at your present desk and what and where before that.	

5 RESULTS

5.1 Teachers' physiological knowledge

5.1.1 Attitudes to the importance of physiological knowledge

Almost all teachers who answered the questions (Table 4) said that more physiological knowledge would be valuable for pedagogical work. However, they were not eager to use physiological terms. Instead of speaking of muscular activity they preferred expressions like:"Try to fill your belt with air!", "Feel loose around your neck!", or "Keep your bottom tight!". They tried to make their ideas understandable by means of musical images, as far as possible.

The youngest teachers were most eager to get more information on the physiology of wind playing. They also believed that information was still lacking on some important aspects. Older teachers and those who had high formal education thought that information existed although they themselves were not acquainted with all of it.

Twenty teachers estimated that physiological knowledge was especially valuable in elementary grade teaching, though its value was acknowledged for all grades of wind studies. The teachers had gained physiological knowledge through their own practical experience as teachers and musicians.

The subjects' own teachers had concentrated on a few obvious physiological problems: the duration of playing, warming up before performance, and flexibility in methods when teaching pupils who were anatomically different from themselves. Proper breathing was considered to be the basis of a good playing technique. Both the subjects and their teachers had also tried to encourage techniques which would prevent the development of disorders of the back and upper extremities.

TABLE 4 The answers of the wind-instrument teachers to the questions about their opinions and knowledge of physiology, and its importance as an aid for teaching.

1.	What is your opinion about the importance of physiological knowledge in wind instrument teaching:	yes	no	?	n
a)	is physiological information useful?	49	2	0	51
b)	is it easily available?	6	43	2	
2.	If you think that physiological knowledge is important, at which level of studies is it valuable	yes		?	n
a)	during elementary grade teaching at music schools?	20		25	49
b)	when teaching students working on a professional degree?	14		-	
3.	How have you achieved physiological knowledge:				n
a)	by reading pedagogical literature?	38			
b)	during your studies?	49			51
c)	through experience as a professional musician?	51			
4.	In your opinion, what kind of physiological knowledge is important for pedagogical work?	- respiratory physiology - knowledge of preventing overuse syndromes			

5. What is the proper location of the breathing associated with wind instrument playing? The subjects were asked to show the pattern of preparatory inspiration they preferred among schematic drawings showing different locations of inspiration (Figure 1).	I 6	II 37	III 8	n 51
6. Which of the following aspects of playing may be adversely affected by faulty breathing: a) embouchure b) finger technique c) playing endurance d) tone quality e) intonation f) playing comfort g) articulation	43 33 51 51 51 51 30			n 51
7. Do you think that physical differences between teacher and pupil (different size or sex) are an adequate reason for changing the teacher of the pupil?	yes 43	no 15	? 3	n 51
8. Have you ever suffered from a) dizziness or b) headache during playing?	29 17			n 51
9. In your opinion, which of the following may result in dizziness or headache: a) stage fright b) muscular tightness c) changes in blood pressure d) lack of oxygen e) hyperventilation	24 24 24 41 31			n 51
10. What is your means to avoid these symptoms?	- good playing position (eg. sitting) - shortening of playing periods - circular breathing			

11.	Are you willing to tell about your daily practice routine? If so, describe it briefly.	yes 48	no 1	? 2	n 51

A low location of breathing was considered to be the basic breathing pattern associated with playing wind instruments. In some extreme tasks, other locations were also accepted: when exceptionally much air was needed, full inspiration was preferred, and in a great hurry also a high location was thought to be practical (Figure 2, Chapter 4.1)..

All teachers considered failures in breathing to be disastrous for playing endurance, tone quality, intonation, articulation, and playing comfort. Five flute players (42%,n=12), six oboe players (32%,n=19), three clarinettists (75%,n=4), and one trumpet player (33%,n=3) felt that faulty breathing may even interfere with finger technique.

The teachers believed that marked anatomical differences between teacher and student may cause misunderstandings. However, according to two female flute teachers and ten male teachers representing both brass- and wood wind-instruments, the difference between males and females, is never so great that it would warrant a change of a teacher. This attitude was most pronounced in the oldest group. In the youngest group, both the male and female teachers felt that it was easier to explain breathing technique when the pupil and teacher were of the same sex and thus physically as similar as possible.

5.1.2 Occurrence of symptoms, their causes and means to avoid them

Dizziness during playing was common in the youngest group of teachers, and even all flute players in this group had sometimes suffered from it. In the oldest group, high-pressure wind players, oboists and trumpet players (86%,n=7) reported having black outs. Headache was not so common as dizziness (Figure 15, Table 5).

Muscular tightness in the neck area was given as a reason for headache by all teachers. Stage fright was also considered a possible reason for this symptom. Fifteen subjects (29%,n=51) felt that any of the suggested reasons for dizziness could be possible: stage fright, changes in blood pressure, lack of oxygen, or hyperventilation. The oldest group considered changes in blood pressure and hyperventilation to be the reasons for these symptoms, whereas the youngest group thought that the reason was stage fright (Table 6).

The methods to avoid dizziness included shortening of playing periods and playing in sitting position. Two oboe teachers said that "circular" breathing was very useful for this purpose too. Circular breathing is a well known method, especially among oboists, to play "forever-lasting" phrases without audible breathing pauses: air flows out from the mouth cavity, which is closed by the tongue in front of the nasal throat, while clean air is inhaled through the nose.

TABLE 4 The number and percentage of the teachers in different instrumental groups suffering from headache and dizziness during wind-instrument playing.

Instrument	n	Players with Headache	Players with Dizziness
Flute	12	4 (33%)	5 (42%)
Oboe	19	6 (32%)	15 (79%)
Clarinet	9	2 (22%)	4 (44%)
Bassoon	1	1 (100%)	1 (100%)
Saxophone	1	-	-
Horn	4	3 (75)%	2 (50%)
Trumpet	3	1 (33%)	2 (67%)
Trombone	2	-	-
Total	51	17 (33%)	29 (57%)

Most of the teachers said that finding the ideal playing position was their key method for avoiding disorders of the back and upper extremities and also for supporting proper the breathing technique.

5.1.3 How teachers themselves practise daily

The teachers divided their daily training into at least two or three periods, each lasting 45 - 90 minutes. Some players told that they warmed up without an instrument before playing. Also, the importance of repeating regularly all the difficult and essential elements of the playing technique was mentioned. These elements include long notes, difficult legato intervals, arpeggios and scales with a variety of articulation. Practising studies, orchestral and soloistic pieces also belongs to the programme.

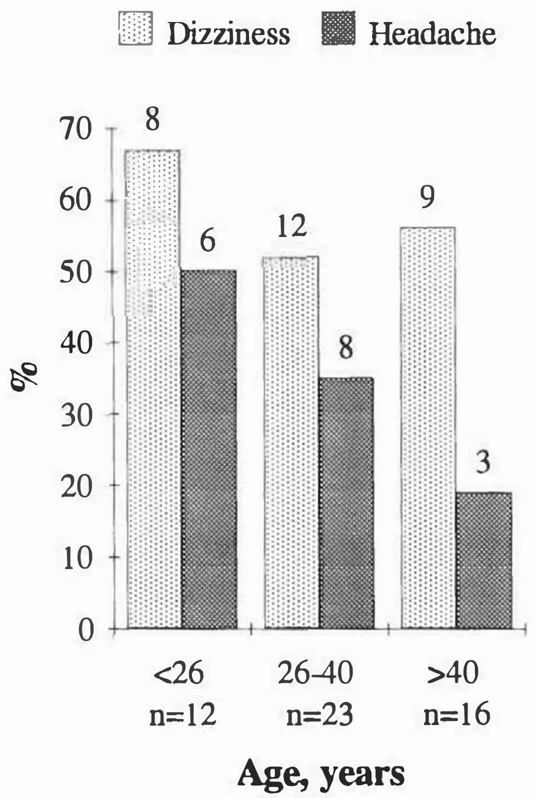


FIGURE 15 The number and percentage of teachers in different age-groups suffering from headache and dizziness during wind-instrument playing.

TABLE 5 Teachers opinions about the reasons for dizziness.

Reasons for dizziness								
Instrument	n	Changed blood pressure		Hyperventilation		Stage fright		
Flute	12	5	42%	8	67%	8	67%
Oboe	19	9	47%	4	21%	7	37%
Clarinet	9	4	44%	2	22%	2	22%
Bassoon	1	1	100%	1	100%	1	100%
Saxophone	1	-		-		1	100%
Horn	4	1	25%	1	25%	1	25%
Trumpet	3	3	100%	1	33%	1	33%
Trombone	2	1	50%	2	100%	-	
Total	51	24	47%	19	37%	21	41%

Although the teachers shared rather similar views about practice, the importance of tiny pauses and the warm-up period was not self-evident to all of them. They advised their pupils to practise in the same way as they did themselves, though perhaps in shorter and fewer periods.

5.1.4 Assessment of difficulties involved in playing different instruments

The main difficulties in playing different winds were felt to be intonation problems, breathing technique, finger or slide technique, and physical stress. The relative importance of these aspects is shown in Figure 16. The teachers gave their assessments using a visual analog scale from 0 to 5

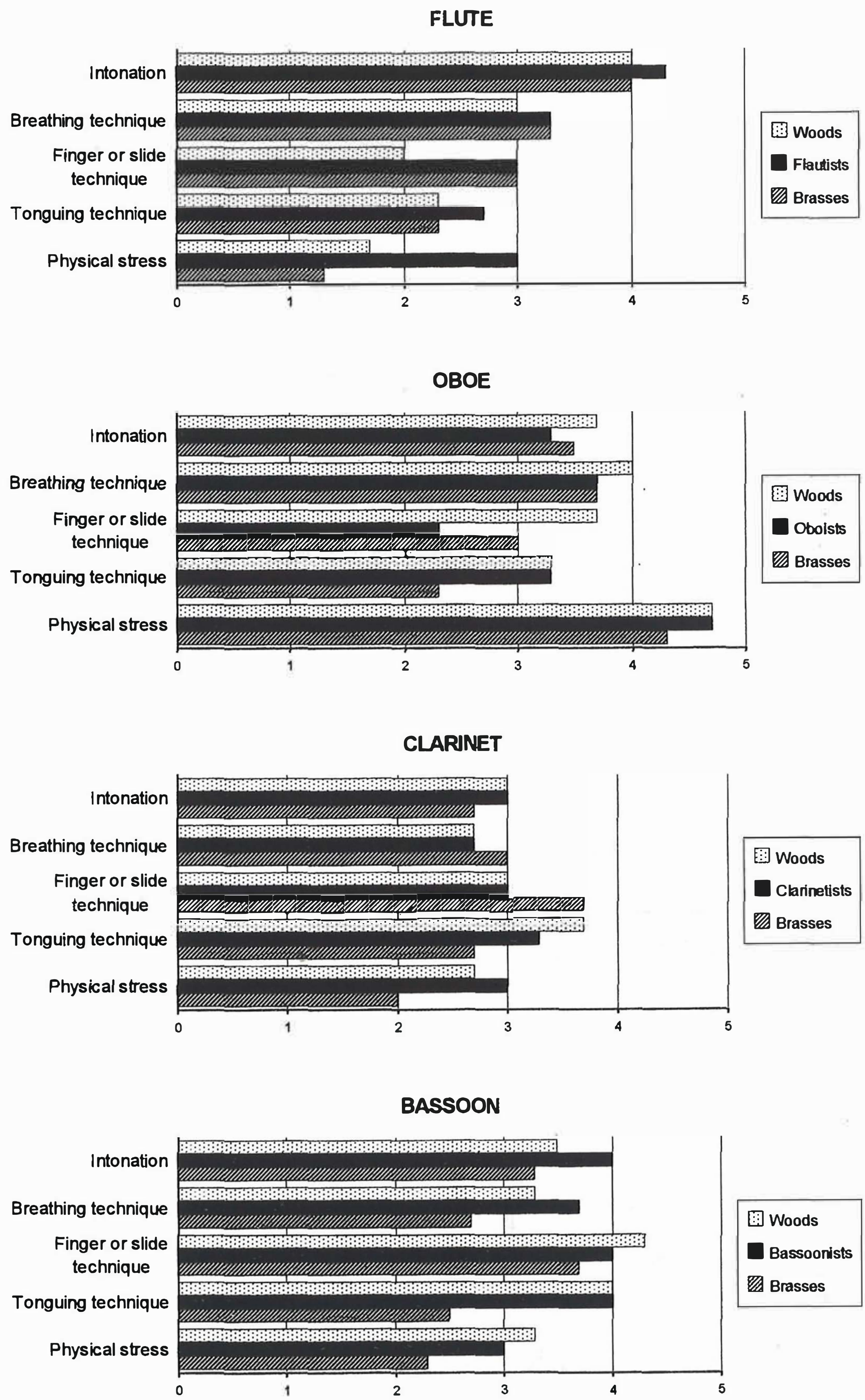
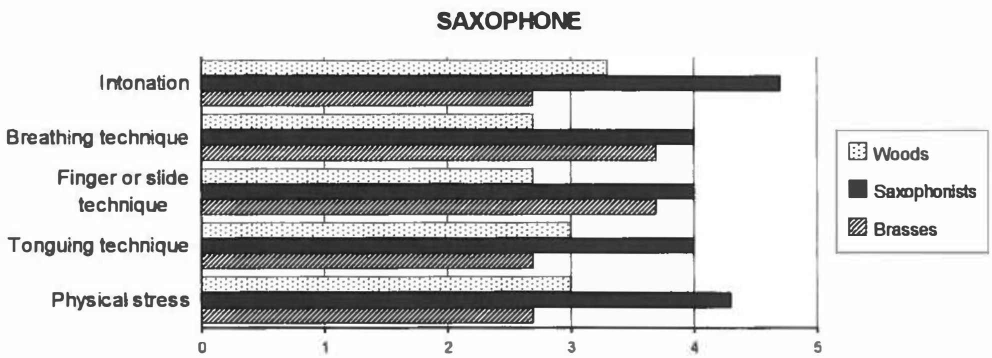
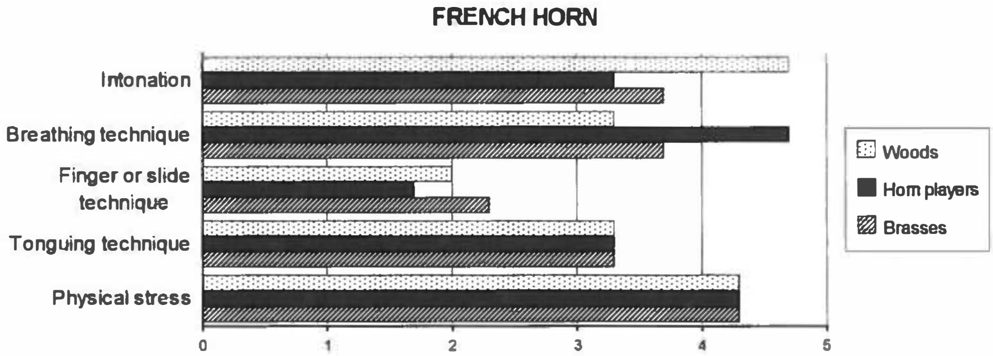
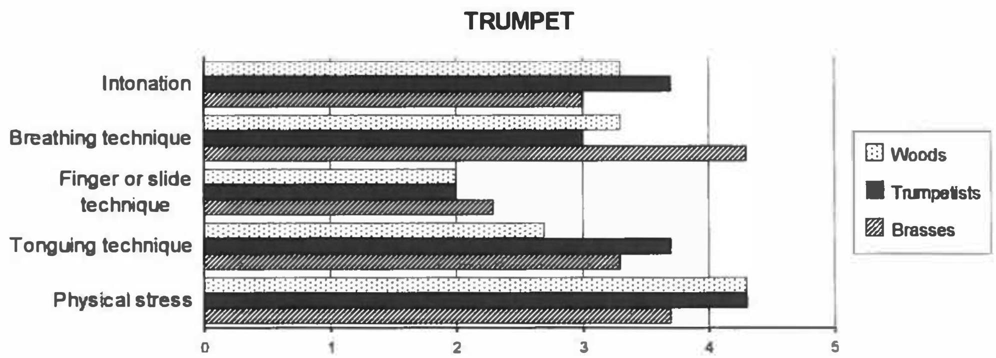
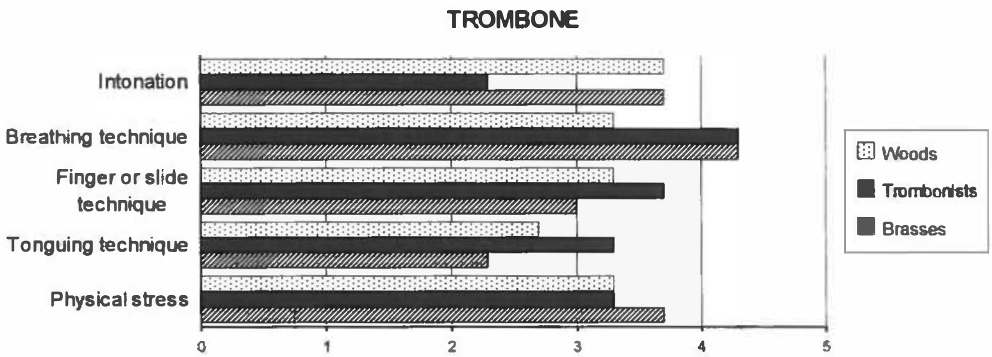


FIGURE 16 Teachers' estimates of difficulties associated with playing different wind instruments. Estimates were given on an analog scale from 0 to 5. Arithmetical mean values were calculated for three groups: specialists (3 players) playing the instrument in question (black bars), and the other









teachers in woodwinds (upper grey bars, 15 players, but without specialists, 12 players) and brasses (lower grey bars, 9 players, but without specialists, 6 players). The saxophone belongs to woodwinds.

5.2 Breathing pattern

5.2.1 Vital capacity

The vital capacities of the subjects were within the normal values (=reference value related to the height and age of the subject +/-20%) in 14 subjects (58%; n=24). Nine subjects (38%) had values above and one wind player (4%) a value below the norm (Figure 17). In normal population the respective percentages are 95%, 2.5% and 2.5%.

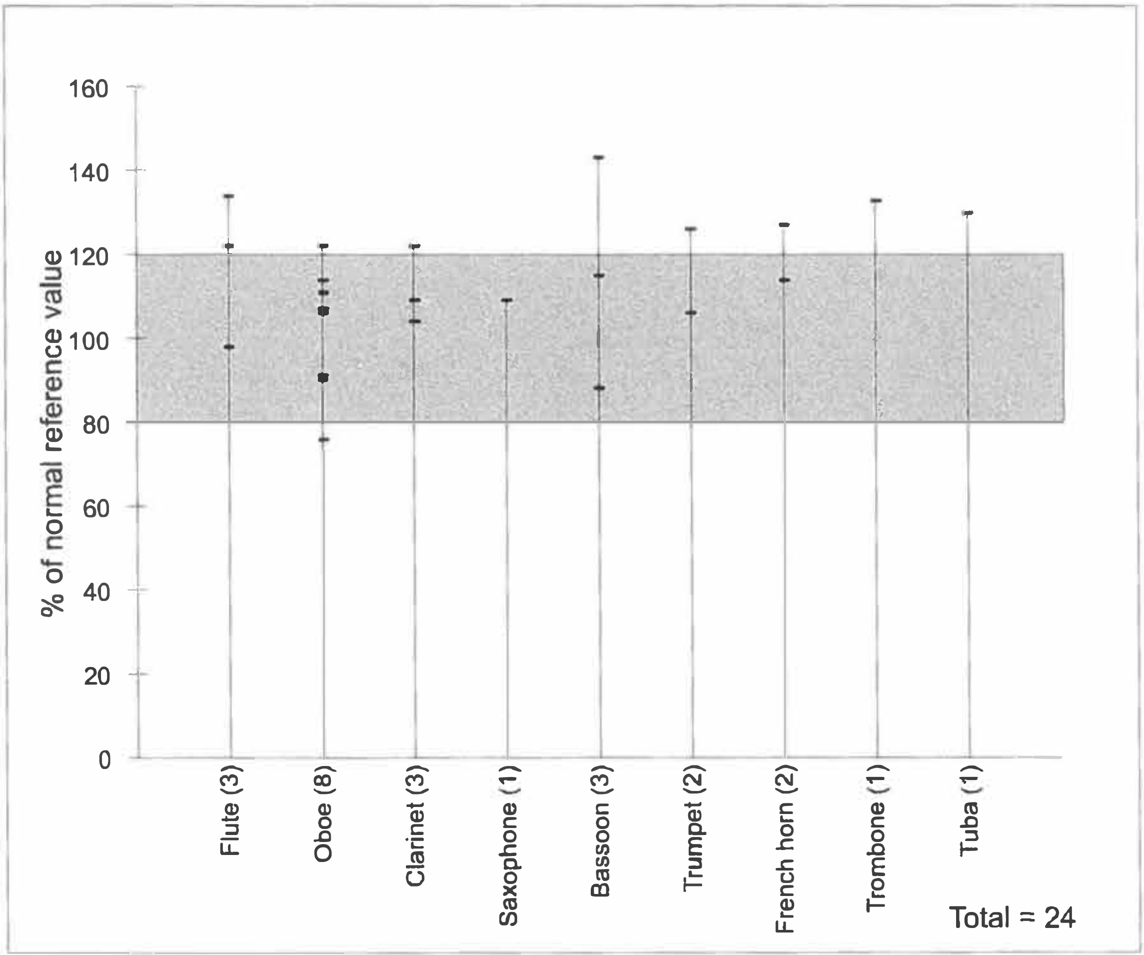


FIGURE 17 Vital capacities of 24 subjects as percentages of age-and-heigth related normal reference values. In the whole population, 2.5 % belong to the group below the grey bar and 2.5 % above it.

5.2.2 Expenditure of air

The expenditure of air while playing long notes is shown in Figure 18. The need of air for sound production differed clearly among the winds. In general, brass instruments expend more air than wood winds. However, the air consumption of the flute was almost constant throughout the registers, and in the high register similar to that of brasses. There were individual differences among the players of each instrument.

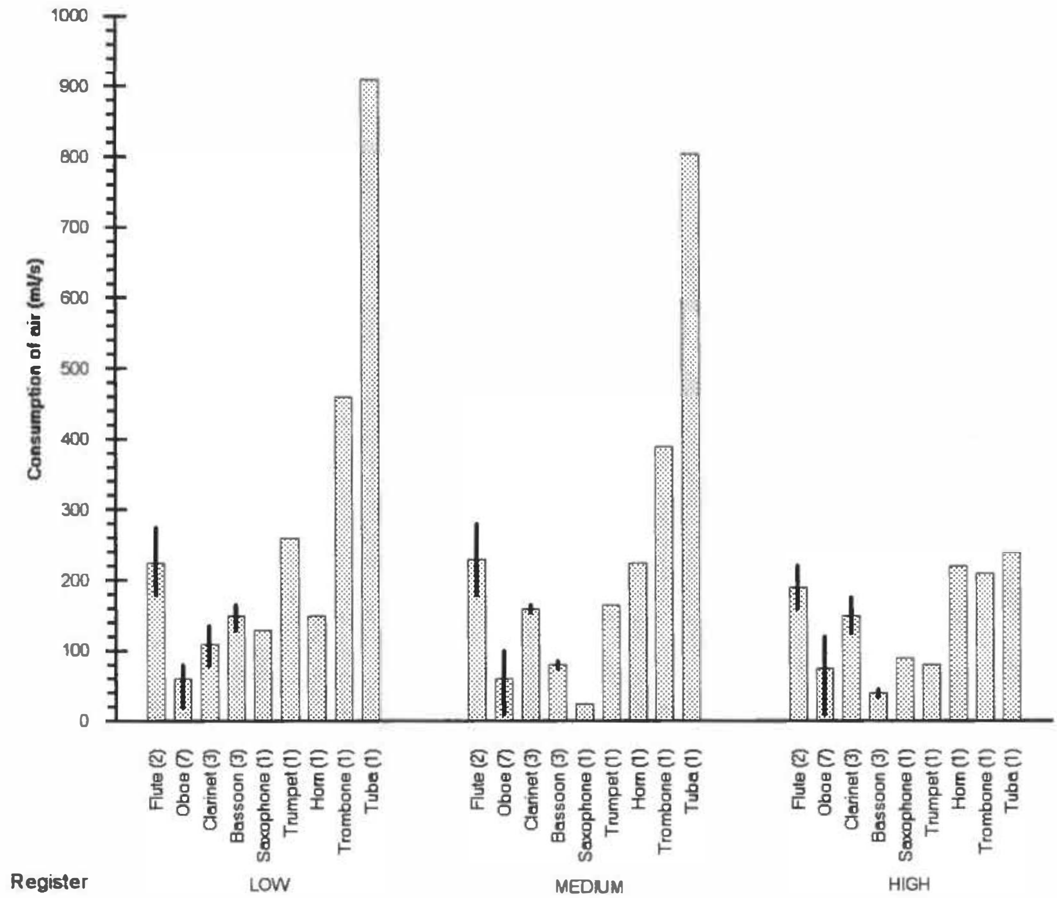


FIGURE 18 Consumption of air (ml/second) while playing long tones in three registers with different dynamics. The bars show the arithmetical means of each instrumental group and the little black lines the range.

When groups of slow staccato notes were played, the lung volumes were found to be larger after than before playing in eight players (53%) and equal in two (13%) out of fifteen (Figure 19). While playing fast staccatos, lung volumes decreased in six players (40%) and increased in nine (60%) out of fifteen (Figure 20).

5.2.3 Blowing pressure

Differences in the blowing pressure among different instruments were marked. In general, a lower pressure was needed for playing in the low register than in the upper register. The clarinet was an exception: its pressure changes did not behave quite so systematically (Figure 21).

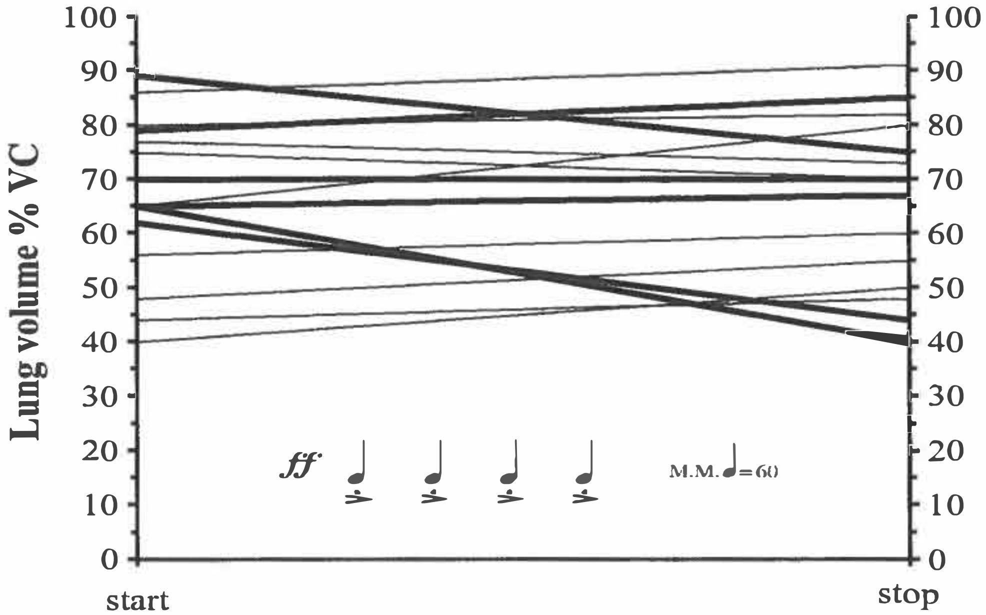


FIGURE 19 Lung volumes in percent of vital capacity beforte and after playing a set of accented staccato notes in slow tempo. The thick lines represent the results of oboe players and the thin lines those of other wind players.

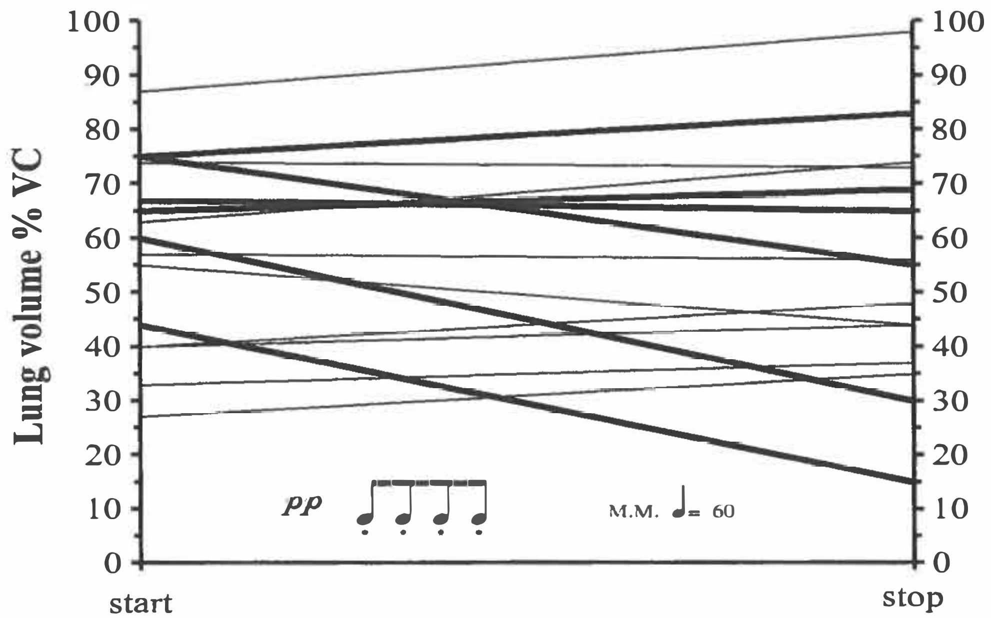


FIGURE 20 Lung volumes in percent of vital capacity before and after playing fast pianissimo staccato notes. Thick lines = oboe players, thin lines = other wind players.

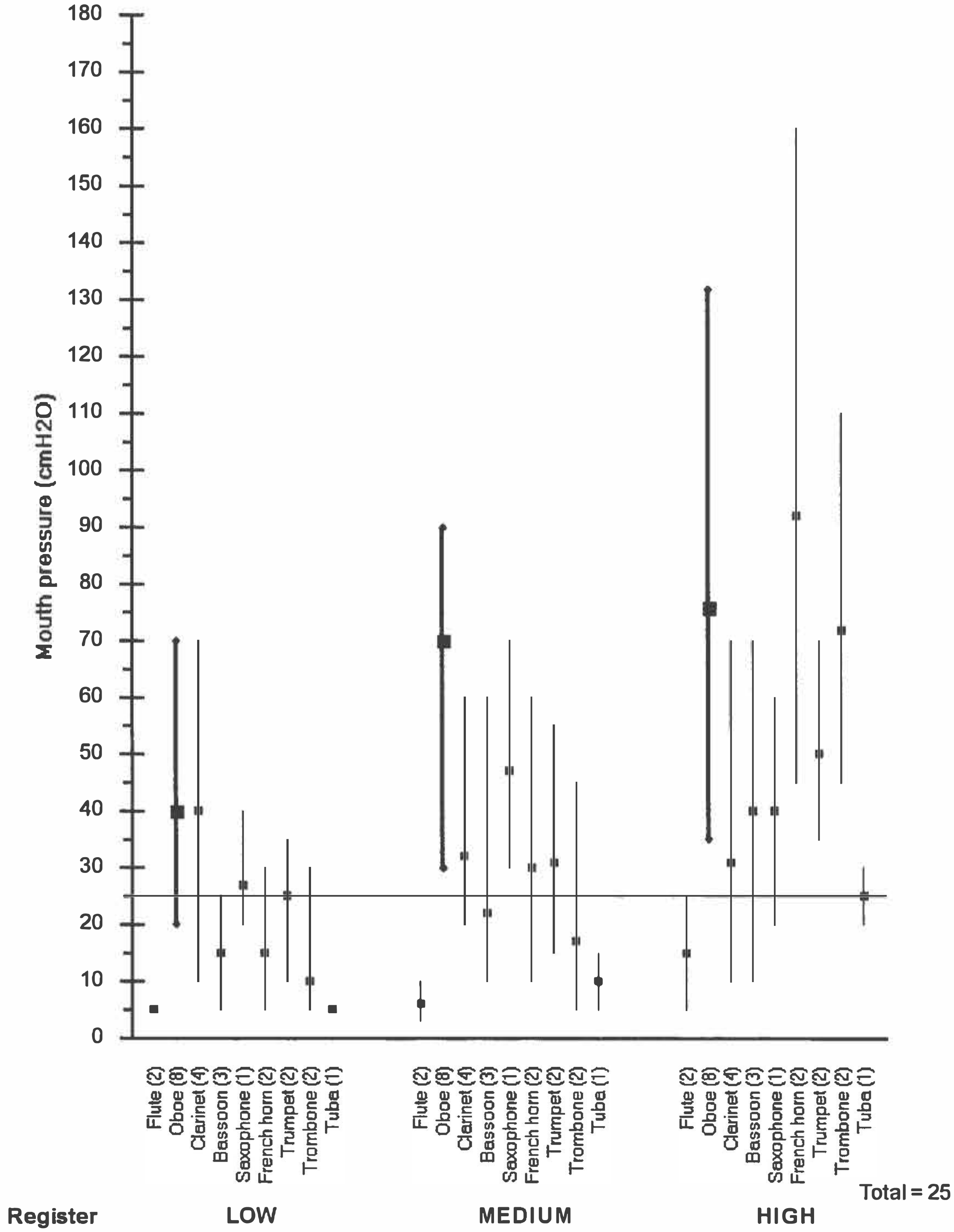


FIGURE 21 Mouth pressure while playing different wind instruments in three registers with dynamics pp, mf and ff. The horisontal line is the upper limit of reasonable continuous pressure strain in the airways. The thick bars represent oboists' airway pressure, the intact lines indicate the range and the squares arithmetical means.

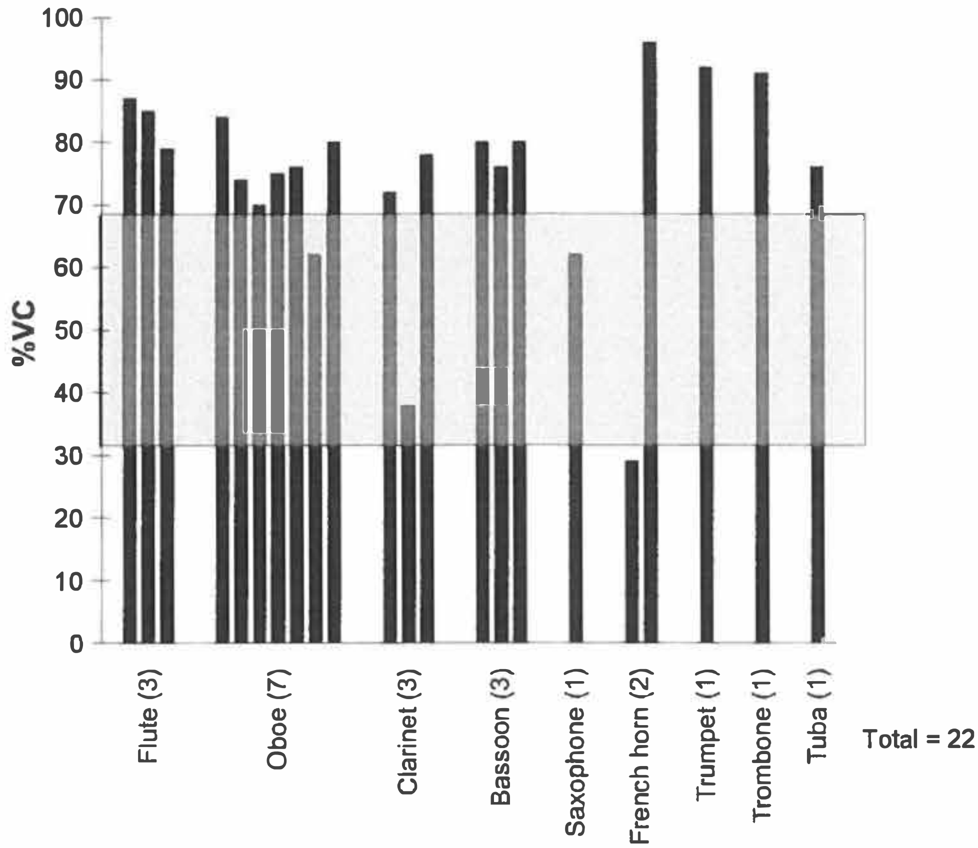


FIGURE 22 The depth of preparatory inspiration of players of different winds before playing a straining solo. The black bars show the depth inspiration of each player in percent of vital capacity, and the grey area shows the range of normal tidal volume in percent of vital capacity.

5.2.4 Lung volumes at the beginning of playing

Two of the professional players said that they try to regulate the preparatory inspiration so that all the air inspired can be expired when playing a musical phrase. Then only inspiration is needed before the next phrase and no more time than necessary is wasted in breathing. Three players, an oboist (n=7), a clarinettist (n=3) and a horn player (n=2), acted according to this idea. Their preparatory inspiration before solos was clearly below the end-inspiratory levels of quiet breathing (Figure 22).

5.2.5 Location of breathing

The preferred breathing patterns were observed from the photos taken of the players who wore the belts measuring chest movements (Table 7). A high location was observed only in one of the 37 players. A low location was popular among the woodwind players, with the exception of the flautists. Deep inspiration was preferred by the brass and flute players. When an oboe player played the recorder, in which he also specializes, he expanded both the upper and lower chest like the flute players (Figure 23).

TABLE 7 Number of players in different instrumental groups with typical location of preparatory inspiration before playing: I - high location, II - low location, III - even location (symbols I, II and III, see Figure 2).

Instrument	n	Location of inspiration		
		I	II	III
Flute	9	1	3	5
Oboe	13	-	11	2
Clarinet	6	-	4	2
Bassoon	1	-	1	-
Saxophone	1	-	1	-
French horn	2	-	-	2
Trumpet	1	-	-	1
Trombone	3	-	-	3
Tuba	1	-	-	1
Total	37	1	20	16

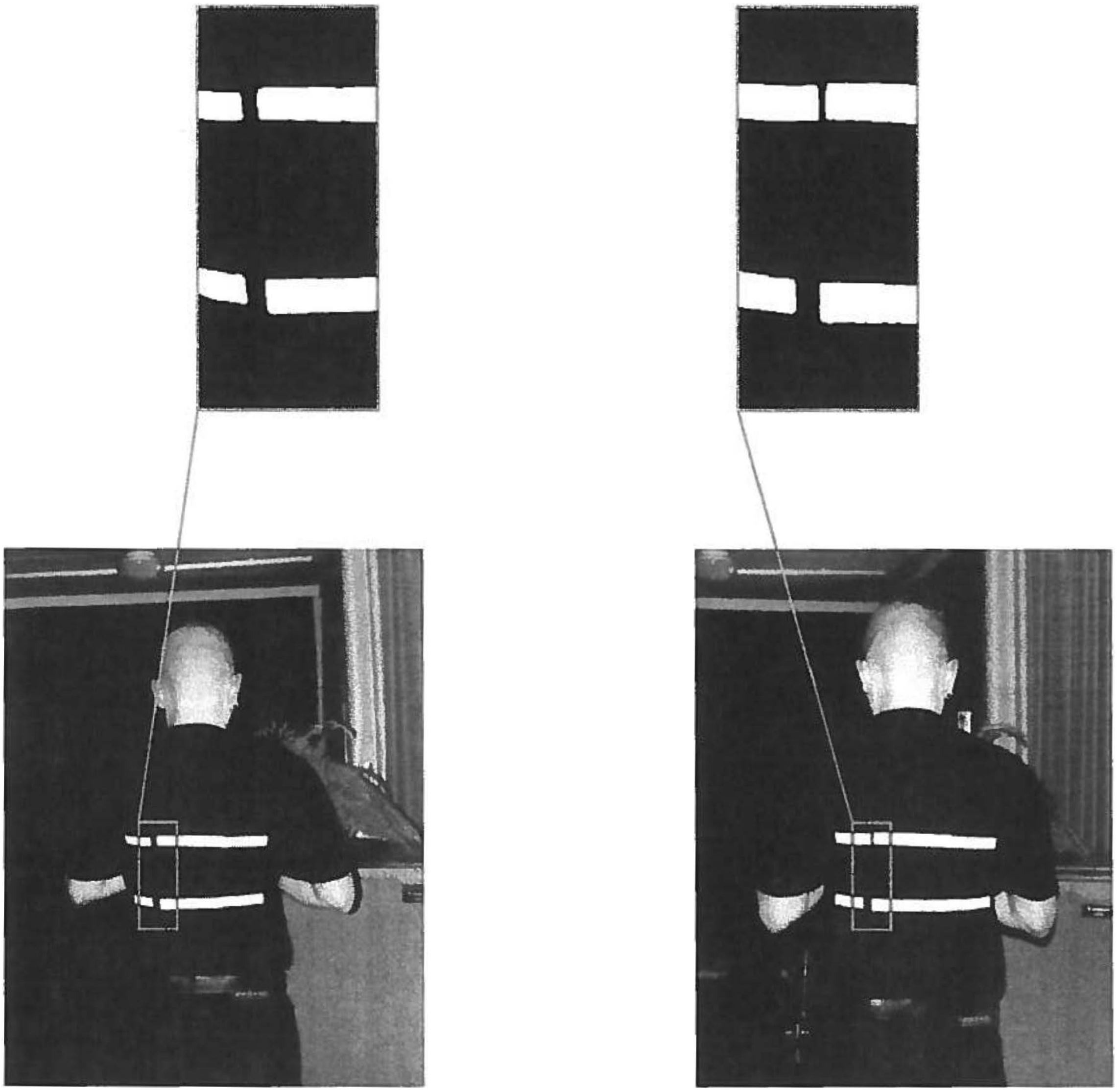


FIGURE 23 Preparatory inspiration shown by means of belts measuring chest movements. For playing the recorder, the whole chest was evenly expanded (left). For playing the oboe the inspiration was mainly located low (right). The same subject played both instruments, and he had majored in both of them at the Sibelius Academy.

5.3 Muscular activity

5.3.1 Muscular activity in musical tasks

Long notes

EMG activity increased towards the end of the playing period when single long notes were played (Figure 24).

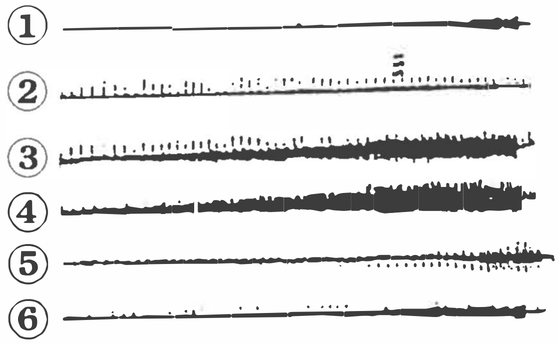


FIGURE 24 EMG activity recorded with six electrodes when an oboist was playing a note as long as possible (here 30 seconds). The activity increased towards the end of the tone. See the location of electrodes in Figure 6.

Chromatic scales

Muscular activity was higher with high-pressure than low-pressure winds at the beginning of the scale when ascending chromatic scales were played. However, the activity increased with both winds towards the end of a phrase. When low-pressure winds were played, the activity was slightly higher for the descending chromatic scale than for ascending scales (Figure 25). The activity changes during playing were otherwise similar in both winds: at

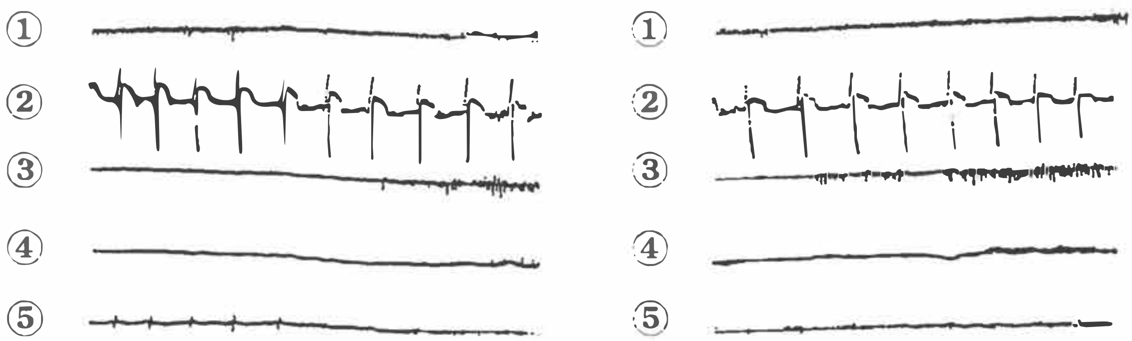


FIGURE 25 EMG activity recorded with five electrodes in a flautist playing an ascending (left) and a descending (right) chromatic scale. In both recordings, the muscular activity increased towards the end of the playing period, (the location of electrodes, see Figure 6).

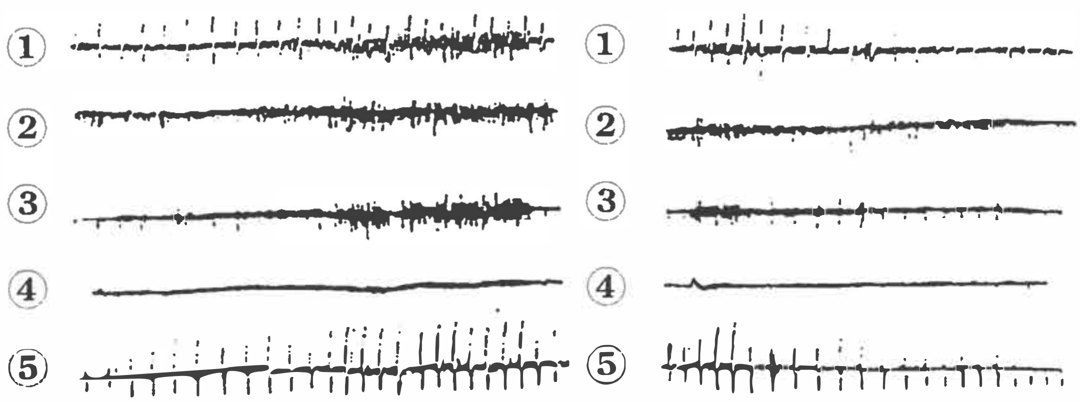


FIGURE 26 EMG activity recorded with five electrodes in an oboist playing an ascending (left) and a descending (right) chromatic scale. The acticity level is more dependent of the register than the phase of playing period /location of electrodes, see Figure 6). The regular peaks show the ECG of the subject.

the beginning there was less activity than at the end. When playing high-pressure winds, the activity was slightly smaller for descending than ascending scales. The activity could also change in the opposite direction , i.e. there was more activity at the beginning than at the end of playing (Figure 26).

Long notes with changing dynamics

While playing a long note with crescendo and diminuendo, the muscular activity followed the dynamics: during crescendo the activity increased and during diminuendo it decreased (Figure 27).

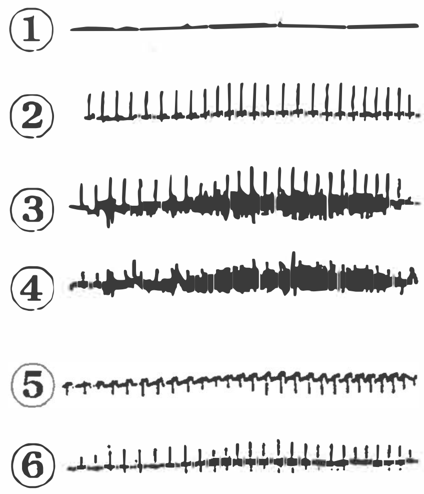


FIGURE 27

A long note with changing dynamics: EMG activity recorded with six electrodes in an oboist playing a long note in middle register with crescendo and diminuendo. Note ECG peaks, and see also "pressure blowing", Figures 32 - 35. (The location of electrodes, see Figure 6.)

Accented notes

Muscular activity increased during accents in all abdominal muscles, mostly in the oblique area but also in the lower and upper parts of the abdomen (Figure 28).

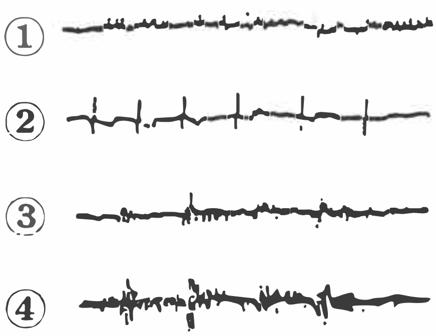


FIGURE 28

EMG activity recorded with four electrodes in a clarinettist playing an accented long note in middle register, (the location of electrodes, see Figure 6).

Staccatos

When light, rapid tongue staccatos were played immediately after a long note, the activity level increased suddenly (Figure 29).

Vibrato

During vibrato playing, rhythmic activity occurred in all abdominal muscles (Figure 30).

5.3.2 Expulsive tasks

All expulsive tasks resulted in visible activity in the abdominal musculature. Spitting demanded moderate activity. Sneezing, laughing, and coughing resulted

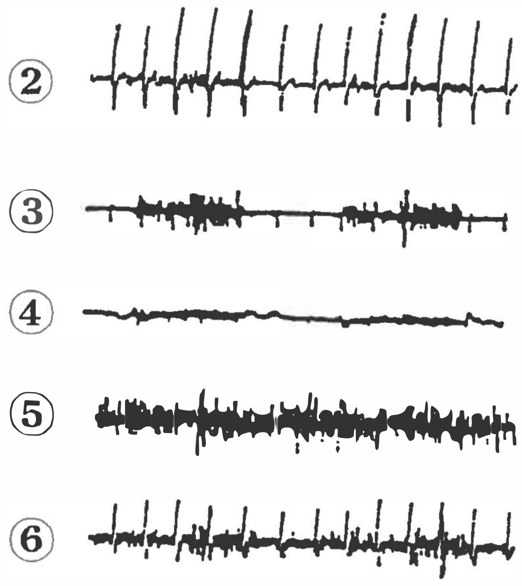


FIGURE 29

EMG acticity recorded with five electrodes in an oboist playing a long note and a following staccato figure. The activity increased abruptly at the transition to staccato, (the location of electrodes, see Figure 6).

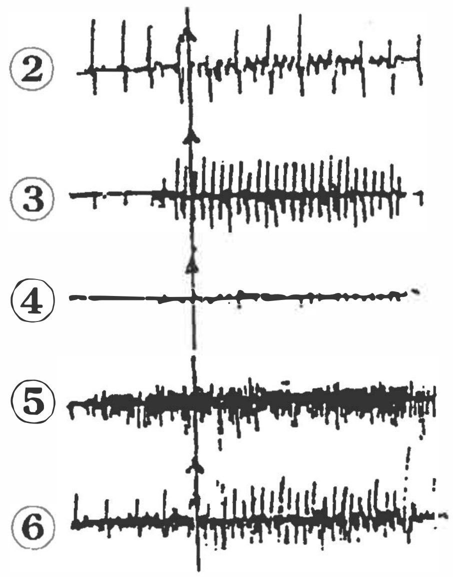


FIGURE 30

EMG activity recorded with five electrodes in an oboist playing vibrato, (the location of electrodes, see Figure 6).

in almost maximal activity in all muscles recorded. An activity change from deep inspiration to expiration was seen during yawning (Figure 31).

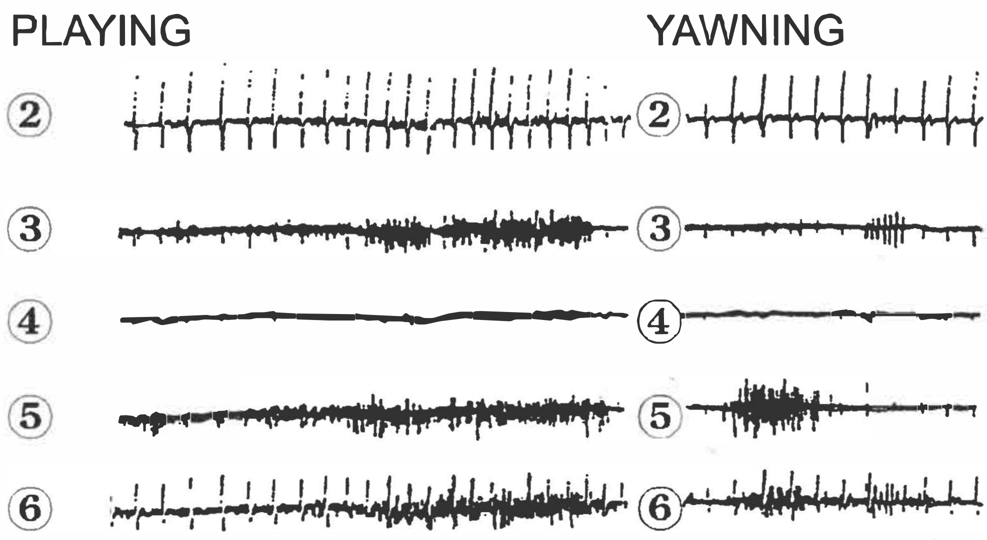


FIGURE 31 EMG activity recorded with five electrodes in an oboist playing (left) and yawning (right). To compare yawning with vibrato, see Figure 30. (The location of electrodes, see Figure 6.)

Pressure blowing

The behaviour of the abdominal musculature was very similar in the musicians and control subjects during the pressure blowing tasks. The activity was clearly higher when the blowing was started at the FRC-level than after deep inspiration. Also, at the FRC-level and after deep inspiration, it was higher during high- than low-pressure blowing. The work of the abdominal muscles was similar in both groups of subjects (Figure 32 - 35).

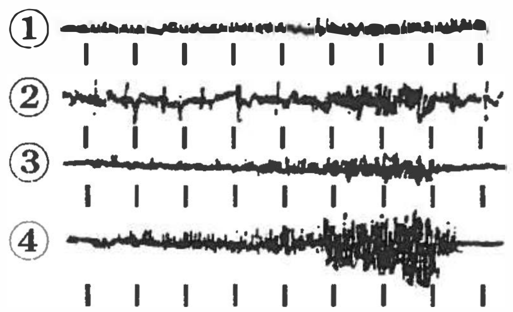


FIGURE 32 EMG activity recorded with four electrodes in a control subject blowing against a low pressure (4 kPa) at FRC level, (the location of electrodes, see Figure 6).

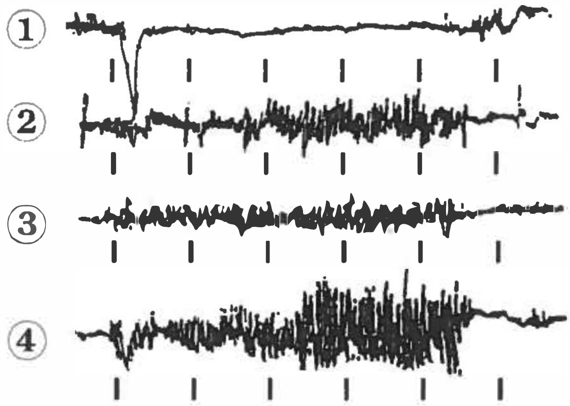


FIGURE 33 EMG activity recorded with four electrodes in a control subject blowing against a high pressure (8.5 kPa) at FRC level, (the location of electrodes, see Figure 6).

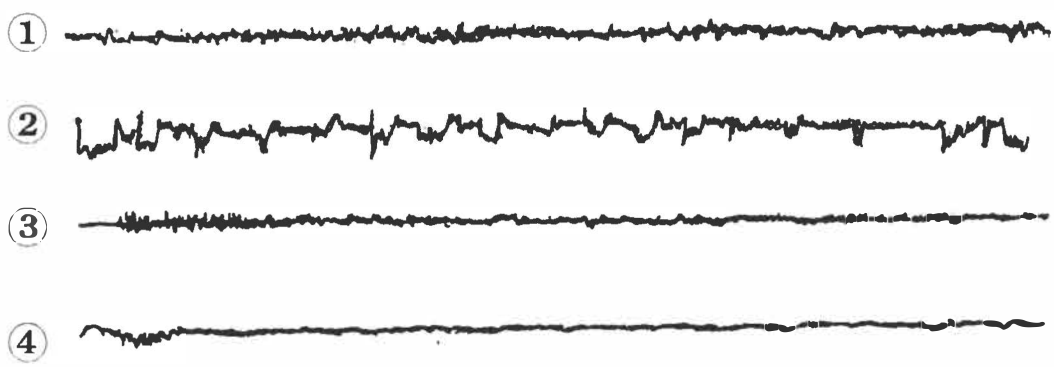


FIGURE 34 EMG activity recorded with four electrodes in a control subject blowing agaist a low pressure after maximal inspiration, (the location of electrodes, see Figure 6).

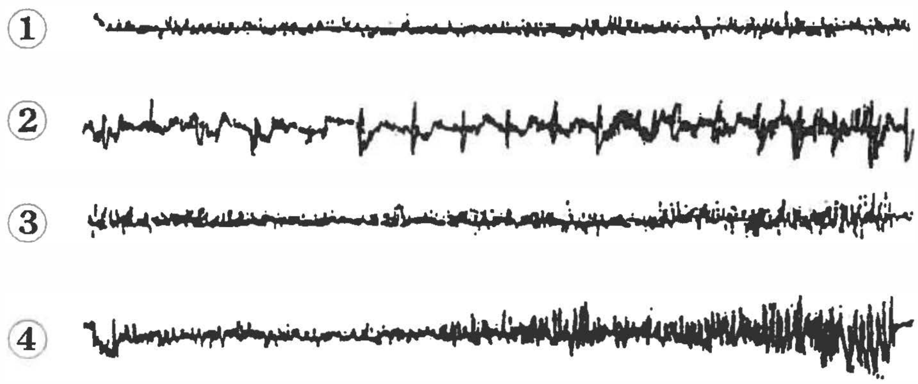


FIGURE 35 EMG activity recorded with four electrodes in a control subject blowing against a high pressure (8.5 kPa) after maximal inspiration, (the location of electrodes, see Figure 6).

5.3.3 Recruitment order of muscles

Individual differences were found in the recruiting order of activation of the recorded muscles. Some subjects brought the whole abdominal musculature into use at once and gradually increased its activity. Others used mainly either the oblique or abdominal muscles. They activated the other muscles only when high overall activity was needed.

The activation of the pectoral muscle followed that of abdominal muscles in many tasks. Also, towards the end of long expiratory phases its activity increased. The trapezial muscle behaved irregularly, except during extreme efforts when its activity increased similarly to that of the other muscles.

The tasks which resulted in the greatest activity resemble the ends of phrases or extreme fortes in musical tasks. The muscular activity needed for spitting was about the same as moderate activity used during musical tasks.

5.4 Intonation

All failures in intonation were taken into account. Discordances were classified according to their type (rapid changes, lasting less than 3 seconds, and slow changes, lasting 3 seconds or more) and location (at the beginning, at the end, or in the middle of notes). The total amount of bias is expressed in cents, one cent being one hundredth of a semitone. In this way, it is possible to operate with equal units throughout the registers without having to consider the frequency differences in semitones. The number of cents in each failure was divided by the number of seconds the failure lasted. Cents per second is thus used as the unit for intonation failure.

The failures ranged between -10 and 15 cents / second. The subjects had some kind of intonation inaccuracy in 31 % of the tones (Table 8)

TABLE 8 Number of false tones, all types of failure (rapid slides to the desired pitch, long slides lasting more than three seconds in the middle of tones, and rapid slides at the release of tones) included. When a single tone was biased in several ways, the slow slide was considered dominant. The direction of the failure was expressed according to the slow slide (+ indicates slides upwards = sharper, - indicates slides downwards = flatter). The number of all false tones in each group is indicated by a number without sign in the middle of each square.

Dynamics	*pp*	*mp-mf*	*ff*	False tones	Total
Register	n=69	n=72	n=72		N=213
Low	+2 5 -3	+1 3 -2	+1 6 -5	+4 14 -10	n=71
Medium	+1 2 -1	+1 3 -2	+1 9 -8	+3 14 -11	n=71
High	+1 8 -7	4 -4	7 -7	+1 19 -18	n=71
Total	+4 15 -11	+2 10 -8	+2 22 -20	+8 47 -39	213

All types of failures occurred most frequently in the high register at high dynamics. Rapid slides at the end of tones were not common. The largest slides were found at the beginning of tones and their direction was mainly upwards (Figure 36). Most of the failures were slow lengthily slides. The majority of them were downwards. They ranged between -3.7 and 3.8 cents / second (Figure 37).

The types of failures varied depending on the type of instrument. For flutes, the failures were always upwards. Failures in both directions occurred when playing the oboe, clarinet, French horn, and trombone. For the rest of the instruments the slides were only downwards. At the beginning of tones, upward slides were the most frequent failures (Figures 38 - 40).

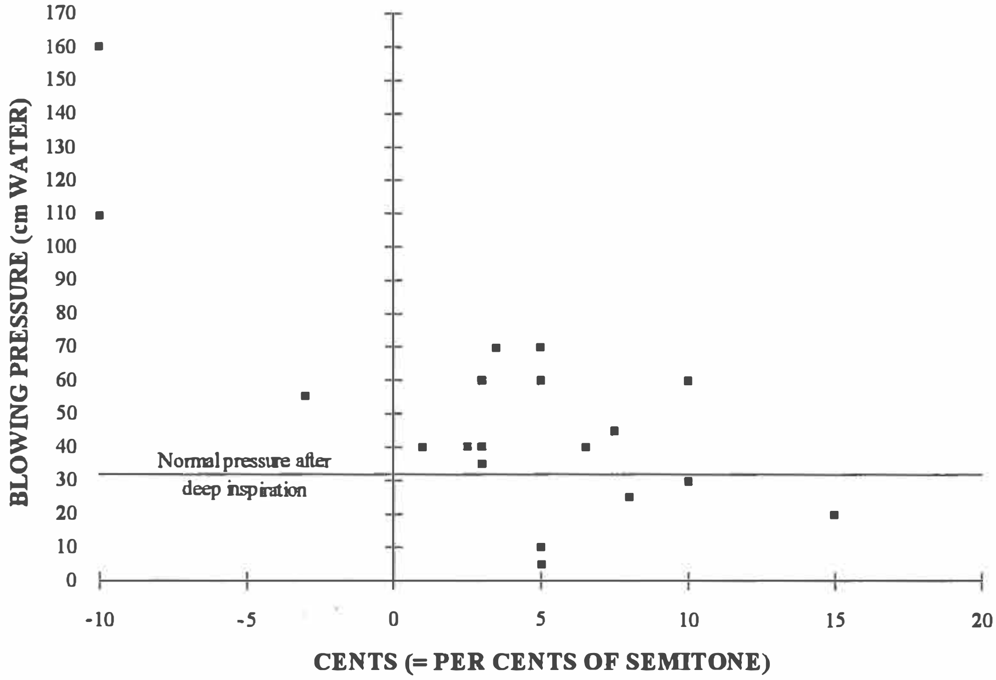


FIGURE 36 Slides at the beginning of tones: + indicates sliding upwards and - downwards towards the desired pitch.

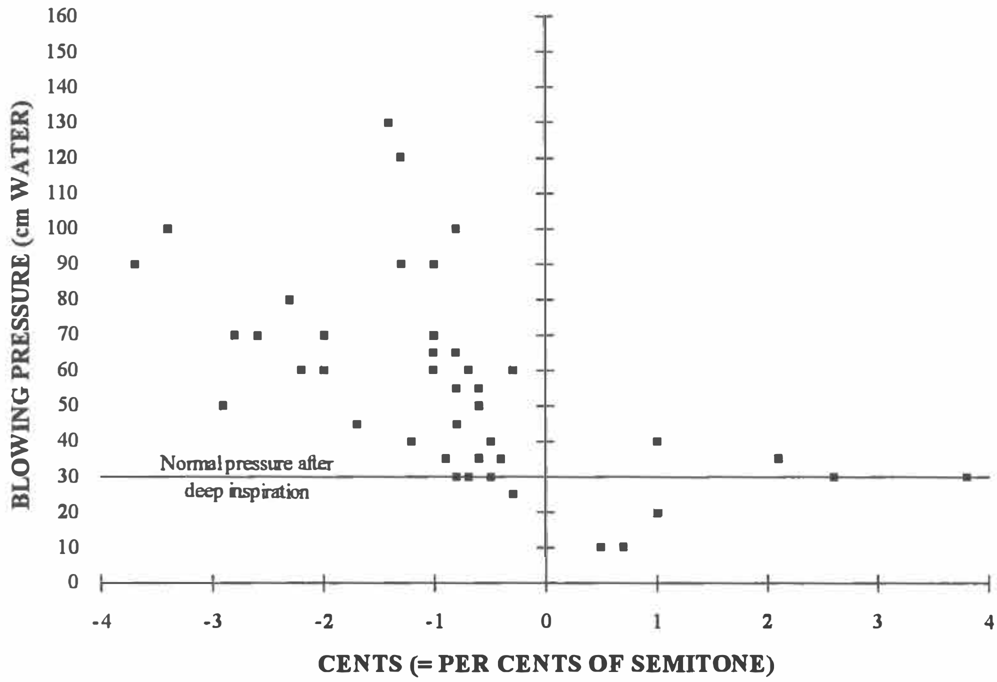
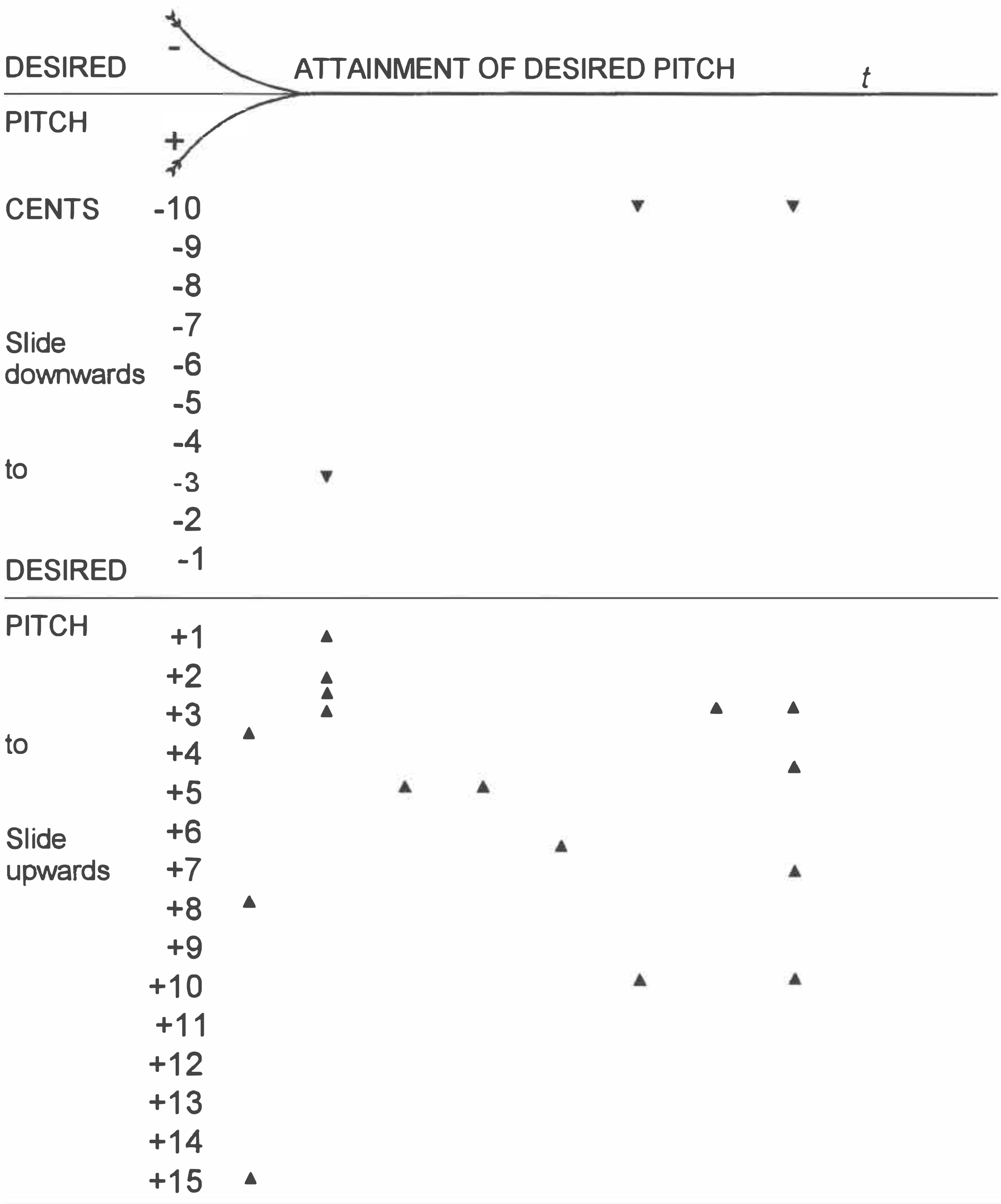
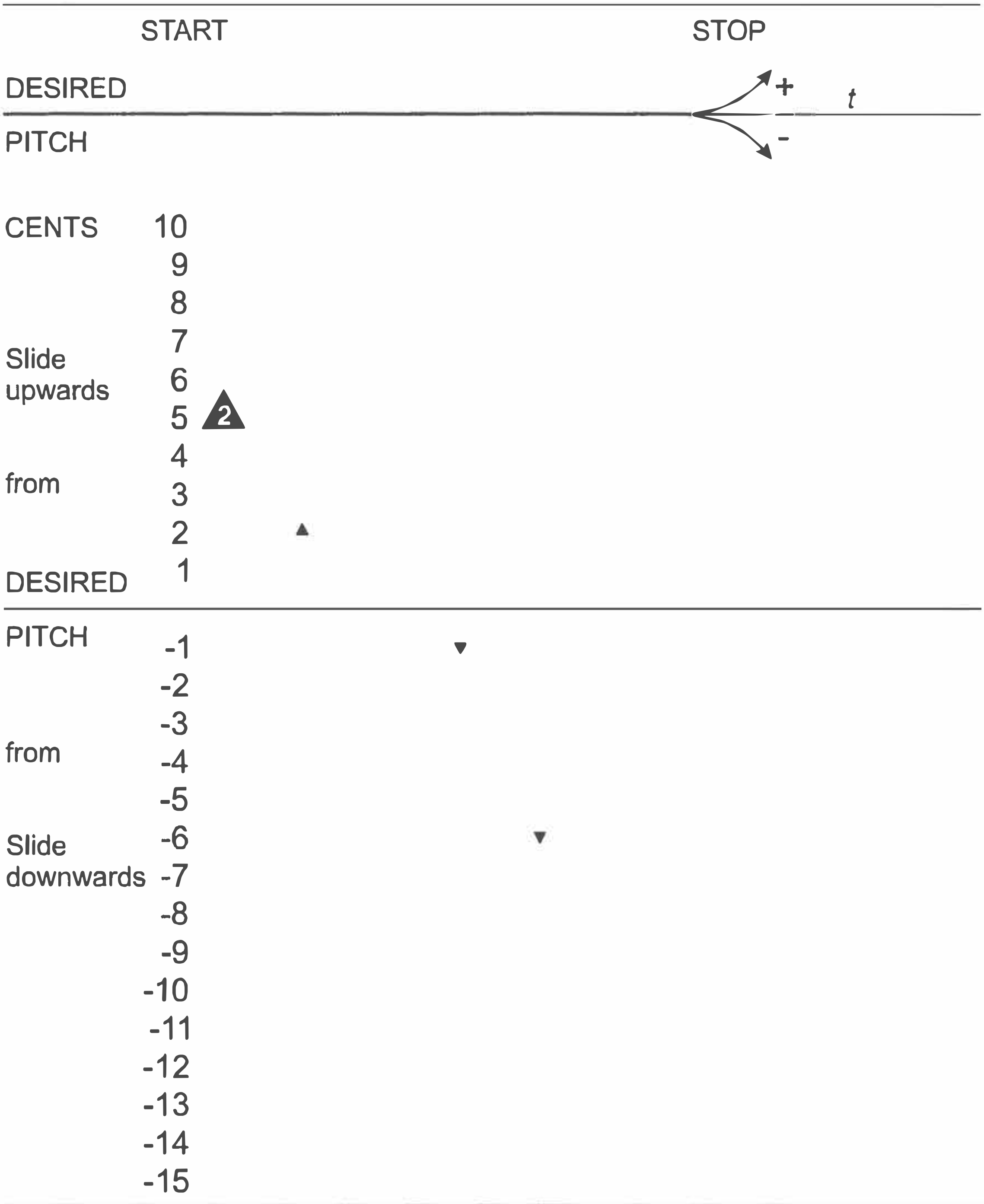


FIGURE 37 Slow slides in long tones at different airway pressures during wind-instrument playing. When the airway pressure was higher than normal airway pressure after deep inspiration, the intonation tended to get flatter (- indicates sliding downwards). When it was near the normal airway pressure, the pitch tended to get sharper (+ indicates sliding upwards).



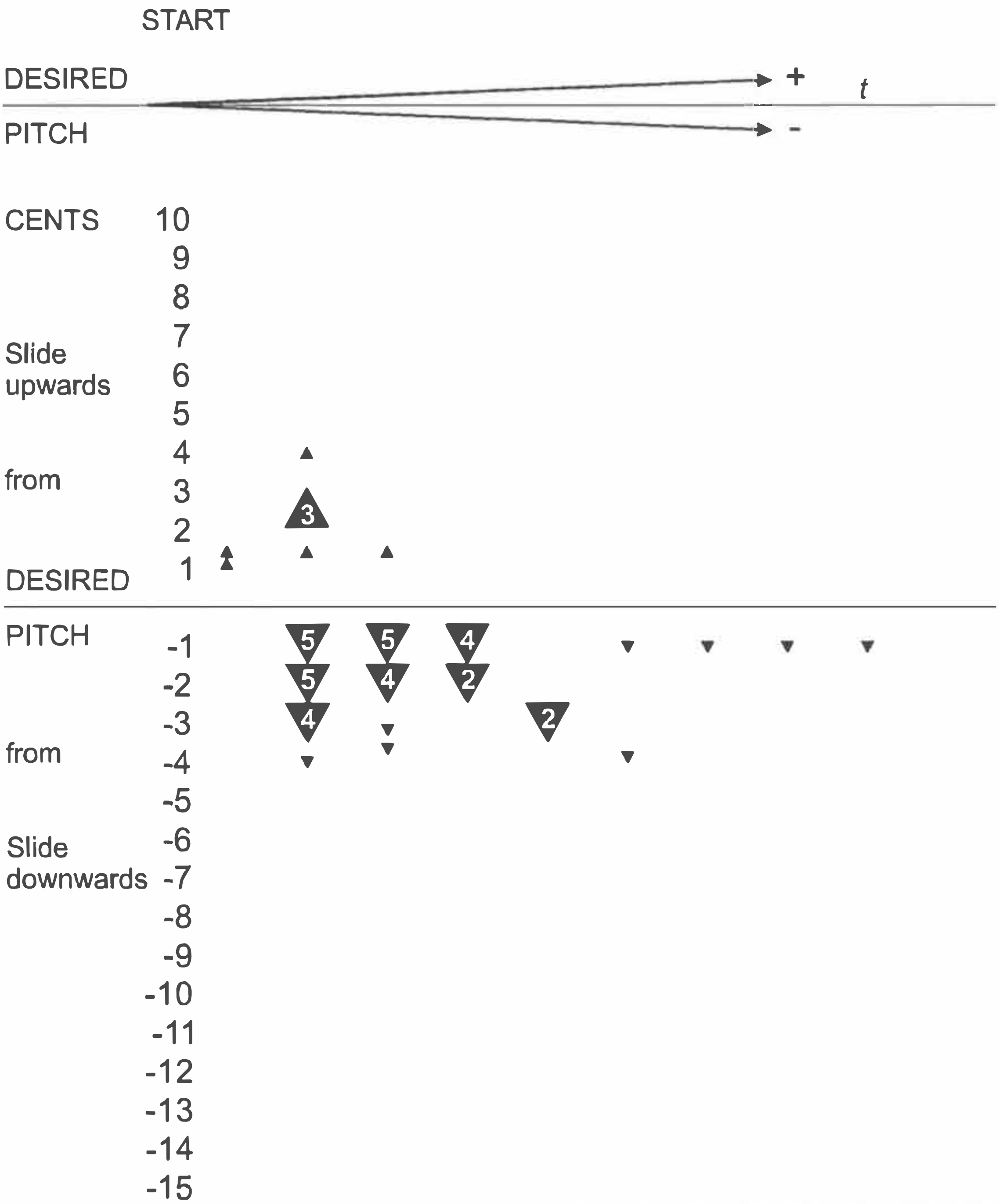
	Fl	Ob	Cl	Bsn	Sax	Horn	Tr	Trb	Tb	Total
Bias	3	5	1	1	1	2	1	5	-	19
n	18	72	33	27	9	18	9	18	9	213
%	17	7	3	4	11	11	11	28	-	9

FIGURE 38 Attainment of desired pitch at the beginning ot tones played with different winds. In Y coordinate zero represents desired pitch. Below zero positive values indicate sliding upwards towards the desired pitch, and above zero,negative values indicate a downward slide towards it. The top of the figure symbolizes the situation.



	Fl	Ob	Cl	Bsn	Sax	Horn	Tr	Trb	Tb	Total
Bias	2	1	-	1	1	-	-	-	-	5
n	18	72	33	27	9	18	9	18	9	213
%	11	1	-	4	11	-	-	-	-	2

FIGURE 39 Slides out of tune at the release of tones. Now + above zero indicates sharpening and - below zero flattening out of tune. The top of the figure symbolizes the situation.



	Fl	Ob	Cl	Bsn	Sax	Horn	Tr	Trb	Tb	Total
Bias	2	20	12	6	2	2	1	1	1	47
n	18	72	33	27	9	18	9	18	9	213
%	11	28	36	22	22	11	11	5	11	22

FIGURE 40 Slow slides out of desired pitch while playing long tones with different wind instruments. Zero in Y coordinate indicates th desired pitch. Negative numbers in Y coordinate indicate sliding (cents/second) downwards and positive numbers upwards out of tune. The top of the figure symbolizes the situation.

5.5 Reeds

5.5.1 Appearance of the reeds

Judged by the appearance, all reeds were related to German reeds. Although the scrape was rather short, some American influence was evident in two reeds: a faint additional W could be seen on them. However, these reeds were classified as U-scrape models. The dimensions of all reeds are seen in Tables 9, 10 and 11.

All the teachers' reeds were very similar in appearance. However, Asser Sipilä's reeds (Ledet 1981) had no close resemblance to any of the present Finnish reeds. This is somewhat astonishing since Sipilä** had taught all the teachers or, at least, their teachers at the Sibelius Academy. On the other hand, almost all Asser Sipilä's students had continued their studies with Kaarlo Pietikäinen* whose reeds belong to the group tested here. Both Sipilä and Pietikäinen studied in Paris, though with different teachers. Therefore, their reeds were naturally influenced by the French model, though each player had adopted different features from it. The younger generation has been mainly influenced by the German, Swiss, Dutch, English and American reed-making tradition. Some of the players have studied in those countries and almost all of them have participated in master classes led by Hans-Wärner Wätzig and Ingo Goritski from Germany, or by Ray Still from the USA.

5.5.2 Pressure demands without lip-control

The material of the cane seemed to play the main role in the regulation of the pressure demands of the reeds. Plastic reeds needed the lowest pressure. Neither were the pressure demands of the fibre-glass reeds as high as those of the reeds made of natural cane. The fibre-cane reeds were reliably classified by the manufacturer: the reed marked with an S needed least and the one marked with an H most pressure.

No single feature alone seemed to play a decisive role in the regulation of the blowing pressure. In pedagogical literature, players have been advised to lengthen the scrape (Reimer 1957; Kaplan & Greiner 1984 eg.) in order to make the reed lighter. The length of the scrape alone, however, had no correlation with the blowing pressure needed for sound generation in the natural reeds studied.

The thickness of the tip and the diameter of its opening correlated positively with the blowing pressure. The tip opening also correlated positively with the blowing pressure (Figures 41 - 43).

TABLE 9 Thichness of scrape in measured reeds: the two numbers in each cell give the measures of the two blades in a reed.

Reed No	A	B	C	D	E	F	G	H	I	J	K	L	M
1	0.10 0.12	0.08 0.09	0.10 0.09	0.32 0.32	0.42 0.43	0.22 0.24	0.38 0.39	0.36 0.42	0.20 0.19	0.46 0.48	0.50 0.45	0.60 0.62	0.46 0.53
2	0.16 0.16	0.14 0.14	0.14 0.12	0.35 0.34	0.39 0.40	0.31 0.32	0.38 0.39	0.39 0.39	0.28 0.27	0.38 0.38	0.47 0.56	0.48 0.51	0.49 0.48
3	0.09 0.12	0.10 0.14	0.10 0.11	0.34 0.43	0.39 0.44	0.28 0.37	0.37 0.43	0.45 0.40	0.34 0.37	0.48 0.50	0.41 0.33	0.54 0.58	0.31 0.44
4	0.11 0.08	0.10 0.10	0.08 0.06	0.38 0.34	0.39 0.38	0.29 0.27	0.36 0.40	0.38 0.36	0.29 0.34	0.44 0.39	0.38 0.44	0.51 0.48	0.47 0.50
5	0.18 0.16	0.10 0.08	0.13 0.19	0.30 0.29	0.40 0.40	0.33 0.39	0.37 0.36	0.36 0.34	0.29 0.29	0.40 0.41	0.55 0.61	0.51 0.48	0.53 0.44
6	0.10 0.07	0.09 0.09	0.09 0.10	0.36 0.33	0.43 0.45	0.26 0.29	0.36 0.28	0.42 0.35	0.30 0.25	0.42 0.49	0.39 0.39	0.53 0.54	0.48 0.45
7	0.11 0.10	0.11 0.09	0.11 0.07	0.33 0.32	0.44 0.44	0.24 0.23	0.38 0.38	0.36 0.37	0.20 0.23	0.49 0.49	0.47 0.42	0.61 0.61	0.52 0.51
8	0.09 0.09	0.10 0.09	0.08 0.09	0.23 0.18	0.38 0.44	0.22 0.25	0.37 0.39	0.37 0.34	0.27 0.23	0.55 0.51	0.36 0.37	0.68 0.63	0.39 0.38
9	0.11 0.10	0.09 0.09	0.10 0.10	0.30 0.31	0.36 0.38	0.22 0.25	0.29 0.35	0.29 0.30	0.22 0.25	0.22 0.23	0.41 0.48	0.58 0.61	0.35 0.38
10	0.18 0.11	0.12 0.13	0.10 0.08	0.29 0.31	0.44 0.44	0.22 0.23	0.41 0.40	0.42 0.38	0.25 0.24	0.45 0.48	0.41 0.41	0.60 0.59	0.45 0.51
11	0.13 0.18	0.14 0.14	0.14 0.13	0.13 0.13	0.32 0.33					0.37 0.38		0.41 0.42	
12	0.15 0.13	0.15 0.14	0.15 0.10	0.15 0.12	0.28 0.33					0.37 0.39		0.41 0.42	
13	0.16 0.17	0.16 0.17	0.16 0.15	0.20 0.21	0.35 0.34					0.43 0.46		0.57 0.57	
14	0.11 0.14	0.13 0.14	0.14 0.12	0.17 0.20	0.27 0.27					0.36 0.34		0.46 0.44	
15	0.12 0.14	0.13 0.14	0.14 0.13	0.18 0.19	0.26 0.28					0.32 0.34		0.47 0.47	
16	0.14 0.14	0.14 0.13	0.16 0.14	0.20 0.18	0.28 0.30					0.35 0.35		0.48 0.47	

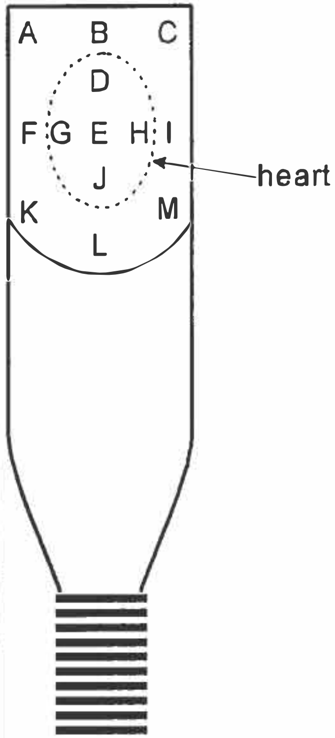
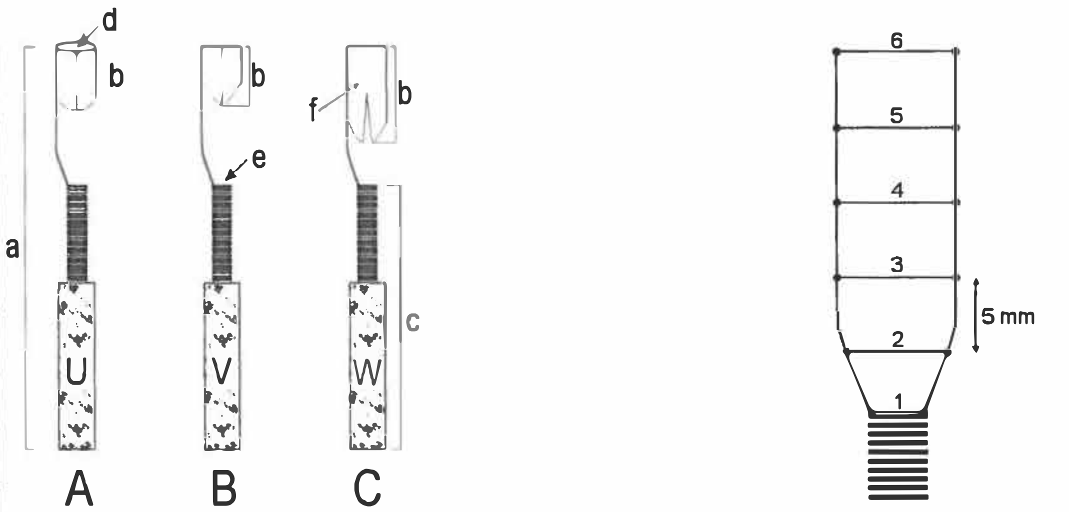


TABLE 10 Dimensions of lengths and breadths of the reeds: the shape of the staple (e) was oval in all reeds; material, if not natural is indicated by P=plastic, F=fibreglass. The b-values are lacking for artificial reeds because they have no separate scrape area in their blades.

Reed No	Length (mm)				Type	Breadth (mm)					
	a	b	c	d		1	2	3	4	5	6
1	72	8.5	46	0.64	U	4.05	5.0	5.9	6.7	6.9	7.25
2	70	10.3	46	1.28	U	4.4	5.4	6.2	6.3	6.9	6.8
3	70.5	11.2	47	0.82	U	4.6	5.8	6.6	7.0	7.0	6.9
4	71.5	10.6	47	0.96	U	4.5	5.8	6.6	6.8	6.9	6.8
5	71	11.0	47	1.25	U	4.5	5.4	6.1	6.5	6.6	6.6
6	72.5	11.0	47	0.79	U	4.3	5.4	6.1	6.4	6.6	6.6
7	71	12.5	46	0.91	U	4.2	5.3	6.2	6.9	6.7	6.6
8	70	9.2	47	0.43	U	4.2	5.5	6.3	6.9	7.0	7.6
9	70	10.0	47	0.89	U	4.2	5.4	6.3	6.7	7.0	6.8
10	71.5	8.7	45	0.83	U	4.2	5.0	5.9	6.4	6.7	6.7
11	67	-	45	0.79	F_S	5.7	6.7	7.3	7.4	7.1	6.4
12	67	-	45	0.73	F_M	5.8	7.1	7.3	7.4	7.2	6.8
13	67	-	45	0.81	F_H	6.1	7.1	7.4	7.3	7.2	6.5
14	70	-	45	0.84	P	5.2	5.8	6.8	7.2	7.8	7.7
15	70	-	45	0.87	P	5.0	5.7	6.5	7.2	7.8	7.7
16	70	-	45	0.49	P	5.05	6.0	6.8	7.6	7.8	7.7

TABLE 11 Arithmetical means of breadths and lengths of each reed type.

Reed Nos	Length (mm)				Reed type	Breadth (mm)					
	a	b	c	d		1	2	3	4	5	6
1-10	71	10.3	46.5	0.88	N	4.3	5.4	6.2	6.7	6.8	6.9
11-13	67	-	45	-	F	5.9	7.0	7.3	7.4	7.1	6.6
14-16	70	-	45	-	P	5.1	5.8	6.7	7.3	7.8	7.7



5.5.3 Intonation failures without lip-control

Six of the professional oboists' ten reeds had a flat intonation without lip control. It was sharp in all artificial reeds, and also in the rest of the natural reeds for at least one note. The values of the pressure and intonation failures are tabulated in Tables 12 - 14.

Through practical experience it has been established (Fitch 1953; Reimer 1957; Tolksdorf & Rösler 1978, eg.) that the deeper the reed is in the mouth the sharper the intonation. If the reed is either somewhat flat or in tune without lip control, it is likely to have perfect intonation when played normally.

The most logically bahaving intonation was discovered in the natural reed which was 71 mm long. It also required a more moderate blowing pressure than most natural reeds. Artificial reeds have the most troublesome intonation. They are also rather short: 67 and 70 mm (Tables 11 and 14).

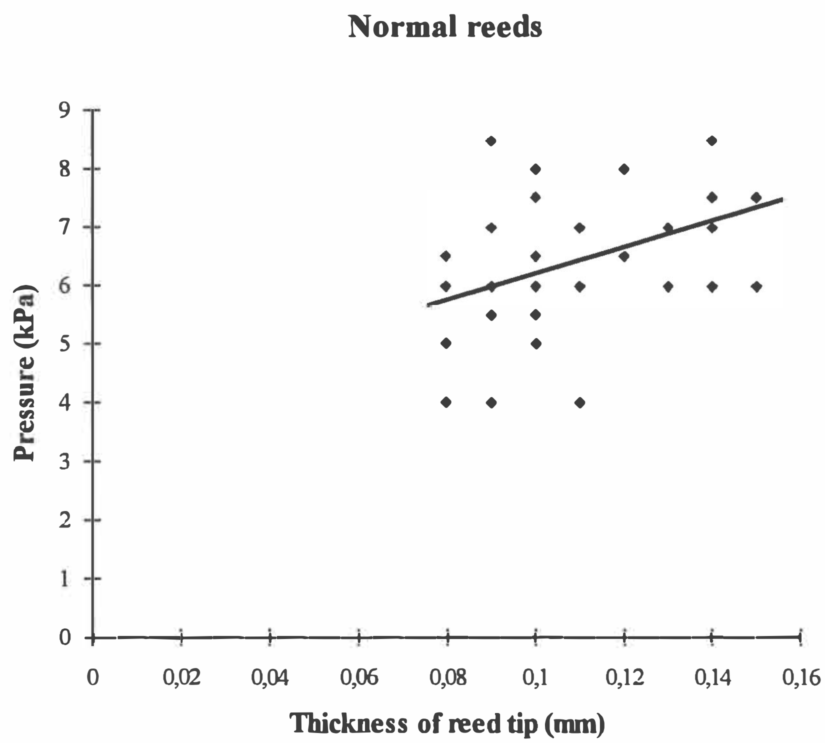


FIGURE 41 Correlation between thickness of tip and blowing pressure without lip control (see Figure 14) at the moment of tone onset in normal reeds.

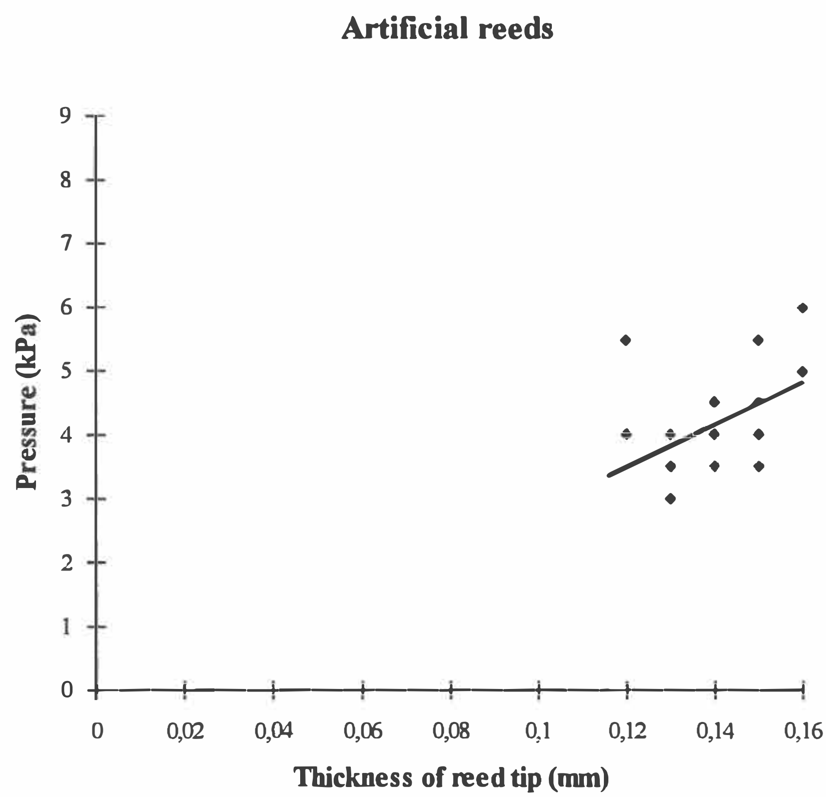


FIGURE 42 Correlation between thickness of tip and blowing pressure without lip control (see Figure 14) at the moment of tone onset in artificial reeds.

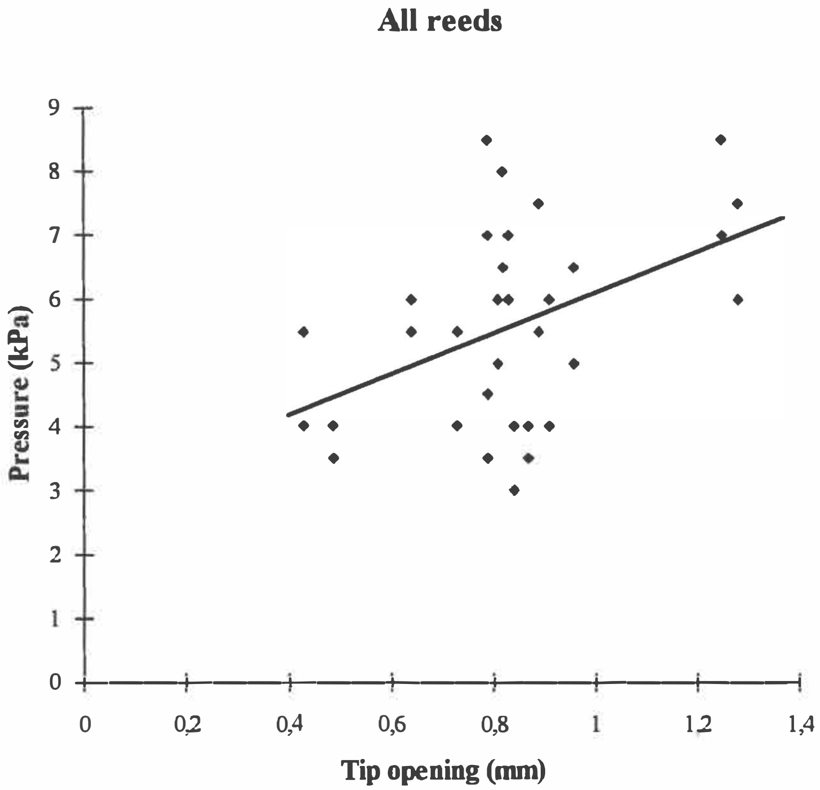


FIGURE 43 Correlation between tip opening and blowing pressure without lip control (see Figure 14) at the moment of tone onset. All reeds were comparable with respect to the dimensions unrelate to material.

TABLE 12 Bias in intonation at the moment of tones onset, without lip control (see Figure 14), when C3, E3, G3 and C4 were played (bias in cents from normal tempered pitch when A3 was 442).

Reed No	Red type	Difference from normal pitch (in cents) in tones			
		C3	E3	G3	C4
1	N	+10	-60	-20	-70
2	N	-	+10	+25	-20
3	N	+5	+15	+5	-5
4	N	-	-15	-15	-20
5	N	-	-25	-30	-50
6	N	-20	-25	-25	-60

Reed No	Red type	Difference from normal pitch (in cents) in tones			
		C3	E3	G3	C4
7	N	-10	-15	-20	-25
8	N	+25	+25	-35	+45
9	N	+15	+20	+5	-10
10	N	+25	-20	+5	-20
11	F	+40	+50	+40	+20
12	F	+25	+35	+25	+25
13	F	+20	+30	+25	+70
14	P	+20	+20	+25	+25
15	P	+75	+10	+10	-
16	P	+30	+30	+30	+25

TABLE 13 Blowing pressures needed to play C3, E3, G3 and C4 without lip control.

Reed No	Red type	Pressure (kPa) without lip control in tones			
		C3	E3	G3	C4
1	N	5.5	6.0	6.0	6.0
2	N	6.0	7.0	7.0	7.5
3	N	6.5	7.0	7.5	8.0
4	N	5.0	6.0	6.0	6.5
5	N	7.0	7.5	8.0	8.5
6	N	7.5	8.0	7.5	7.5
7	N	4.0	5.0	6.0	6.0
8	N	4.0	4.5	5.0	5.5
9	N	5.5	6.0	7.5	7.5
10	N	6.0	7.0	6.5	6.5
11	F	3.5	4.0	4.0	4.5
12	F	4.0	4.5	5.0	5.5

Reed No	Red type	Pressure (kPa) without lip control in tones			
		C3	E3	G3	C4
13	F	5.0	5.5	5.5	6.0
14	P	3.0	3.5	4.0	4.0
15	P	3.5	4.0	4.0	4.0
16	P	3.5	4.0	4.0	4.0

TABLE 14 Reeds tabulated in intonation and pressure categories. When the pressure, needed to produce the note of the triad, increased in equal steps from note to note along the ascending scale, the pressure behaviour was as expected (Table 13). Likewise, when the intonation became regularly flatter in equal steps along the ascending scale, the intonation behaviour was as expected (Table 12).

Intonation categories / **Pressure categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A					15 P	16 P 11 F	14 P	
B	7 N					12 F	8 N	13 F
C		4 N	2 N	1 N 9 N				
D		5 N 6 N	10 N		3 N			

5.6 Adaptation

5.6.1 Breathing patterns before playing

Three types of changes in breathing patterns were found among the wind-instrument players: an increase in the frequency of breathing (Figure 44), a gradually increase of the FRC level (Figure 45) and a double peak in inspiration just before playing (Figure 46). Changed preparatory breathing was found in 93%

of all subjects tested. The percentage distribution of each change and of their combinations are seen in Figure 47.

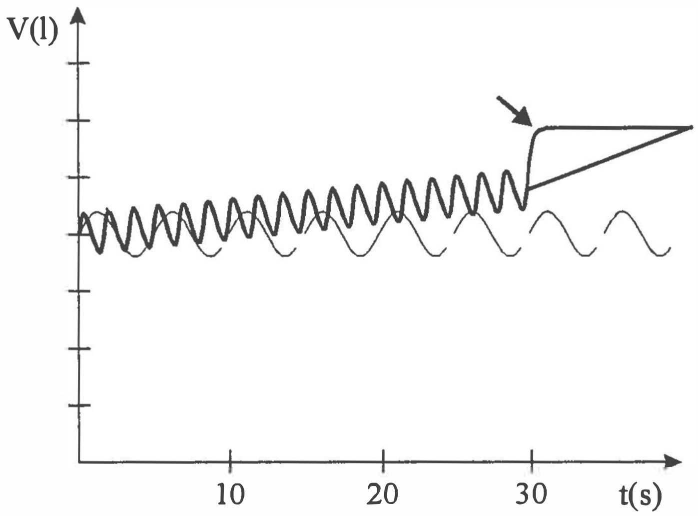


FIGURE 44 An example of change in the breathing pattern preparatory to playing a wind instrument: respiratory rate increases and FRC level ascends. (Reconstructed.)

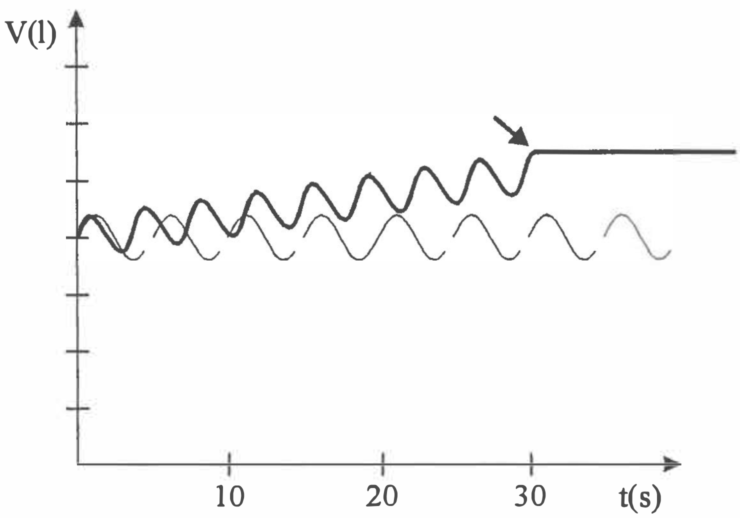


FIGURE 45 Preparatory change in wind instrumentalist's breathing before playing: FRC level ascends gradually. (Reconstructed.)

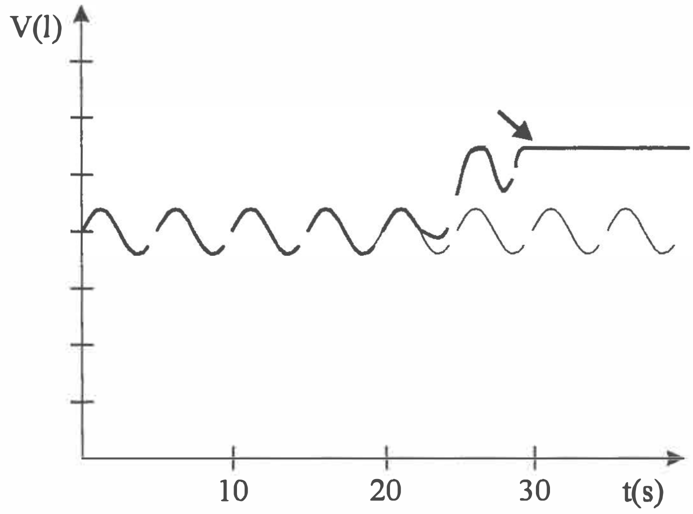


FIGURE 46 Two peaks in a wind player's TV just bebore playing. (Reconstructed.)

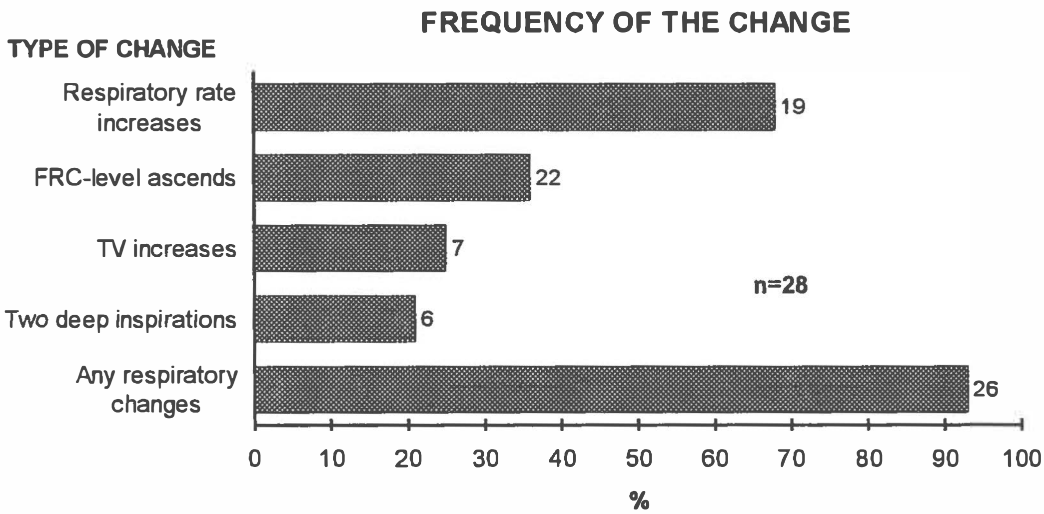


FIGURE 47 Percentage of four types of respiratory changes preparatory to playing in 28 wind players.

5.6.2 Tidal volumes in rest

A large tidal volume and a low respiratory frequency were found to be more common among musicians than medical students.

5.6.3 Heart rate reactions during Valsalva tests

The wind players' Valsalva ratio was below the normal values in all players when calculated on the basis of the heart rate reaction during the first fifteen seconds of pressure strain. When the calculation was based on the maximum heart rate during a prolonged pressure strain, the ratio was either normal or nearly normal (Table 15 and Figure 48).

TABLE 15 The results of wind players in the Valsalva test. The test was made using three pressure levels corresponding to the strain during playing. The strain level of 4.0 kPa was almost the same as that at which the age-related reference values (= in parenthesis, the numbers are minimal values of normal ratios) were obtained (Piha 1988). The Valsalva ratios of all wind players were lower than the reference values. When the pressure and test duration increased, the reactions approached the normal values. The number of subjects in recordings varied because of the difficulties with the equipment.

Code of subject	Pressure (kPa)	Valsalva ratios	
		15"	30 - 45"
a	2.5	1.42	1.14
b		1.03	1.08
c		1.40	1.40
d		1.26	1.26
e		1.44	1.44
f		1.90	2.11
a	4.0	1.50 (1.61)	1.50
b		0.99 (1.44)	1.09
c		1.45 (1.61)	1.76
d		- (1.65)	-
e		1.44 (1.61)	1.56
f		0.99 (1.74)	1.21
a	8.5	1.78	2.19
b		-	-
c		1.86	2.44
d		2.00	3.02
e		2.01	2.24
f		1.96	2.39

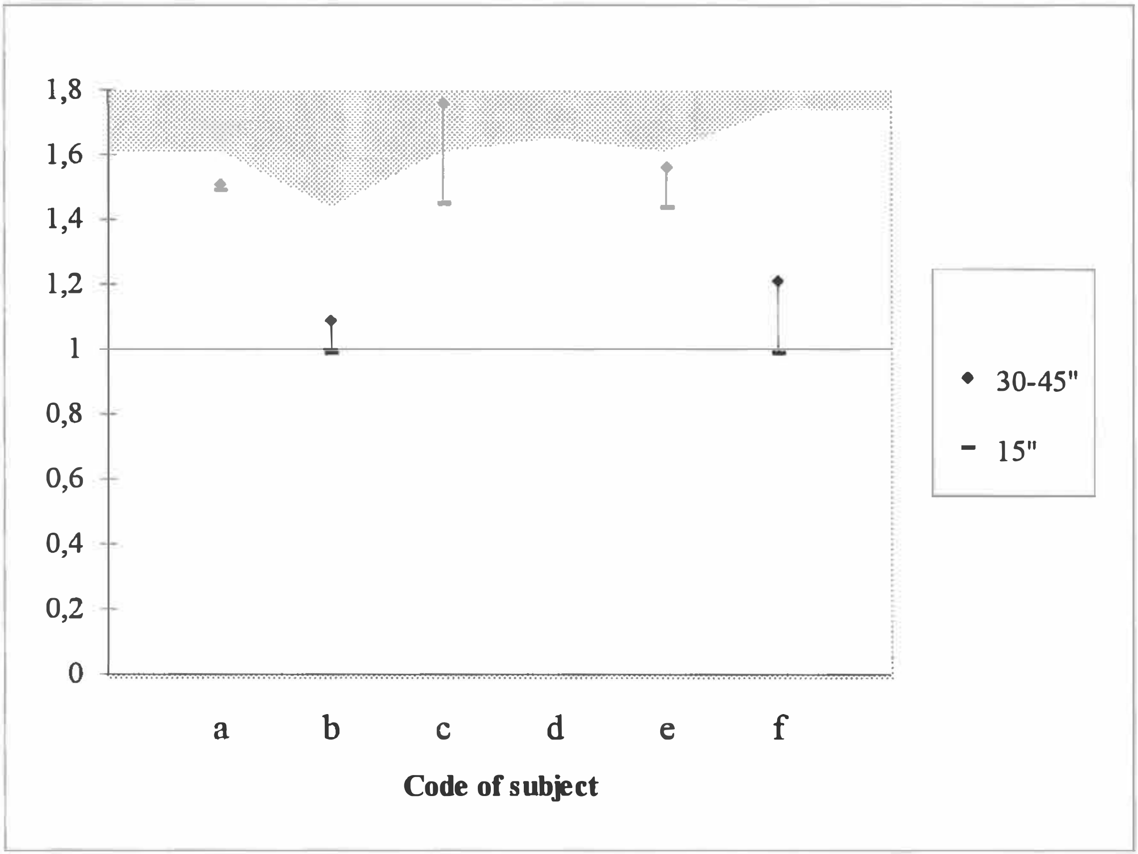


FIGURE 48 The change in Valsalva ratio in wind players, when blowing against the pressure of 4.0 kPa. Normally the ratio is determinedafter 15 seconds from the onset of the pressure strain. In these subjects, the phases were prolonged. The maximal tachycardia was reached 30 - 45 seconds after the onset of pressure blowing. In subjects b and f, the bradychardia phase occurring before tachycardia is still present at the moment when maximal tachycardia is normally reached (Piha 1989). The grey space in the figure shows the normal Valsalva tachycardia area. The line indicates normal heart rate without pressure strain. Bradycardia occurs in the area below the line.

5.7 Subjective experiences of occupational symptoms

5.7.1 Stage fright and self-confidence

The wind instrumentalists reported more often than the other musicians that they suffered from severe stage fright (winds 15%, others 5%). Weak self-confidence among symphony winds had been earlier reported (Teirilä & Salorinne 1990). All interviewees were of the opinion that stage fright caused difficulties in respiration, a sticky mouth, tachycardia, tremor, headache, dizziness, cramps, stiffness, cold hands, increasing sweating, and weakness (Table 16). Some players included insomnia and stomach disorders in this group of symptoms, too.

TABLE 16 The percentage of players in different instrumental groups suffering from symptoms caused by stage fright.

Symptoms caused by stage fright	Wind players n=59	Other players n=56	Total N=115
Tremor	20 (34 %)	25 (45 %)	45 (39 %)
Cramps Stiffness	10 (17 %)	9 (16 %)	19 (17 %)
Palpitation	9 (15 %)	8 (14 %)	17 (15 %)
Breathing problems	15 (25 %)	-	15 (13 %)
Increased sweating	10 (17 %)	6 (11 %)	16 (14 %)
Dizziness	6 (10 %)	6 (11 %)	12 (10 %)
Dry mouth	10 (17 %)	3 (5 %)	13 (11 %)
Weakness	7 (12 %)	3 (5 %)	10 (9 %)
Cold hands	5 (8 %)	3 (5 %)	8 (7 %)
Headache	1 (2 %)	4 (7 %)	5 (4 %)
Exhaustion	5 (8 %)	1 (2 %)	6 (5 %)

5.7.2 Means to avoid symptoms of stage fright

Several kinds of methods are used by players to avoid stage fright and its harmful effects on performance: more musical training, drugs blocking beta receptors, psychological training, rest and sleep before performance, healthy habits in general, alcohol before performance, diet, self-suggestion, yoga, avoidance of coffee. The beta-blockers mentioned were Propral, Trasicor, and Inderal. Only some of the players remembered the dose, which they reported to be between 5 mg - 40 mg propranolol.

Allergic diseases were most common among the wind instrumentalists: 20% of the wind players mentioned them, while the percentage was only 5 % among the other players.

6 DISCUSSION AND CONCLUSIONS

6.1 Physiological knowledge

The assessment of the role of different physiological factors in wind playing was the main aim of this investigation. It also focused on the usefulness of physiological information in pedagogics. To accomplish the latter aim, the first task was to find out what the teachers knew about the physiology of playing, and how they had acquired this information as their soloistic or pedagogical studies did not include physiology. Questioning was a natural way to disclose the means by which teachers solved the problems inherent in physically demanding musical tasks.

The results obtained by interviewing or by a questionnaire are difficult to interpret because of the problems involved in the measuring of attitudes. Then there are also problems related to the sample. The teachers participating in this investigation were the best professionals in Finland. Thus the results obtained by interviewing them do not tell how wind students are taught throughout the country. However, they offered a better basis for the experimental investigations of the present study than those obtained from less experienced teachers would have done.

The breathing pattern associated with wind-instrument playing and the ergonomy of musical performance were the only technical factors that were regarded as physiology by the teachers. The meaning of the term physiology was obviously not familiar to the teachers: instead of associating it with all aspects of bodily functions, they rather used the term as a synonym for either anatomy or pathology. The descriptions of daily practice revealed a tendency to regard the playing technique as something separate from physiological phenomena. Their own routines were not adopted in the original form from published collections of daily studies. However, the teachers roughly followed the programmes introduced in these books. No explanations were given about the aim of the exercises from the physiological point of view.

The majority of the teachers considered the physical differences between teacher and student so critical that they could even be a reason for changing the teacher. However, the oldest teachers thought that the physical sex differences could never be so marked that they would warrant a change of teacher. This view has a natural explanation: only for a few years has it been possible to get a female teacher for wind instrumentalists.

All the teachers acted as members in examination boards evaluating instrumentalists of different winds. The special problems related to the playing of different winds seemed generally to be well understood. However, subjective factors may influence the work of wind players' examination boards. All instruments are different with respect to their acoustical demands. This is not, however, appreciated by all members of the boards. Thus the players of the instruments requiring the greatest physical effort are likely to become unfairly treated. To avoid injustice, it is important that all members of examination boards have proper knowledge of the physical properties of different wind instruments and their physiological demands on the player.

According to wind teachers, physiological knowledge is especially valuable in elementary grade teaching. This opinion is easy to accept because the physiological model of playing technique is created during the elementary grade studies. If faulty manners are adopted during this time they can disturb playing throughout the whole career.

6.2 Breathing patterns

Laboratory artifacts were possible in the experiments on the respiratory functions associated with playing. When spirometry is used for studying air expenditure during wind-instrument playing, the results may be influenced by some uncontrolled factors. These include changing the mouthpiece to another before and after playing which may result in an attempt to store some extra air. Also, leaks may occur during the transfer. Therefore, the players were allowed to make several attempts until they felt they mastered the situation.

The exact and valid measurement of vital capacity was important in this study, because the only comparable manner to analyse the results from subjects of different sizes was to use percentages of their vital capacities. Therefore, care was taken that the subjects mastered the blowing to the spirometer.

During the pressure measurements, a thin tube was used to ensure that the embouchure was disturbed as little as possible. A balloon on the tip of the tube was used to prevent saliva from flowing into the tube. However, those players who felt that the balloon interfered with their embouchure so much that the playing was seriously troubled were allowed not to use it. As a consequence, saliva plugged the tube during some measurements and those recordings had to be rejected. The measurements which were judged as failures by the players were also discarded. Because all participants faced the same problems, the results can be considered to be at least satisfactory for the evaluation of the differences and similarities among the pressure and flow demands of wind instruments.

6.2. Lung volumes

Playing low-expenditure winds (Roos 1936) resembles holding one's breath. Perhaps this is the reason why some wind teachers prefer very low lung volumes when starting playing. At high volumes, proprioceptor stimuli start the expiratory drive (Mountcastle 1978; West 1983), and this may disturb a player when he has to maintain a prolonged expiratory phase (Cohen 1970).

Most players, however, started their solos at high lung volumes. This is easy to understand because with high-expenditure winds one has to inspire enough air to be able to play the whole phrase in one expiration.

Between staccato notes there is always a tiny rest. Because the expenditure of air during one single note is small, players may inspire little during the rests. This may explain the paradoxical increase of lung volumes during staccato playing.

6.2.1 Lung compliance

Many subjects playing high-pressure winds inspired far over the normal end-inspiratory level before playing a long solo. There are at least two good reasons for doing this: at high lung volumes, lung compliance helps to develop the necessary pressure without any physical effort. At a slow respiratory rate, deep breathing is essential to keep minute ventilation adequate. Expirations between phrases are then necessary.

Though it is probably easy to hold one's breath or to keep the slow air flow steady at the FRC level (Viljanen 1970), this method results in no spontaneous pressure production. This means that muscular work is needed to generate the pressure essential for playing. When the lung volume decreases, even slowly, the muscular work needed to maintain a steady pressure increases. The lower the lung volume is at the beginning of the phrase, the sooner the physical effort needed exceeds the player's capacity. With respect to high-pressure winds, this means that the lower the inspiratory level the shorter the phrase.

6.2.3 Location of inspiration

The receptors causing the Hering-Breuer inflation reflex in a normal adult are stimulated when the tidal volume exceed one litre (cf. Cohen 1970; West 1983). Then also the upper part of the chest cavity is expanded. It is therefore natural that players prefer a low location of inspiration before playing. Maximal inspiration without widening the upper parts of the chest cavity makes it easier to produce the pressure needed with lowest possible expiratory drive.

With practice the diaphragm can be made to move more efficiently. Thus it is understandable that players favour a low location of inspiration. With an efficient use of the diaphragm and the lower intercostals, it is possible to reach high lung volumes without stimulating the proprioceptors of the upper parts of the chest cavity. Lung compliance is called into action to help in pressure production.

6.2.4 Distribution of ventilation and circulation during playing

When the pressure in the airways is high, above 2.0 kPa most of the time, there is hardly any blood flow in the upper parts of the lungs (Mountcastle 1980). The only area where both perfusion and ventilation can then be effective is the lowest part of the lungs. Therefore, low breathing is reasonable during high-pressure wind playing.

6.2.5 Differences among instruments

The pressure-flow demands of different instruments offer an explanation for the differences in the inspiratory patterns required for playing them. On the basis of this investigation, orchestral wind instruments can be divided into four groups according to their physiological demands: 1. low-pressure winds with moderate expenditure of air; 2. winds which occasionally demand high pressure but which most of the time, especially in the mid register and moderate dynamics, require moderate pressure and expenditure of air; 3. high-pressure winds with minimum expenditure of air; 4. instruments which require high pressure in the high register and low pressure in the low register but almost continuously high expenditure of air. Differences in the location of inspiration can thus be explained by the different physiological demands of each instrumental group.

1. The players of instruments requiring low pressure and moderate expenditure of air often preferred even inspiration. During flute playing, the expiratory phase is longer and the inspiratory phase faster than during quiet breathing. The frequency of the respiratory rate is also decreased. The airway pressure is, however, all the time within physiological limits. Therefore, it is possible that breathing is not disturbed by anything else but a slight change in minute ventilation. Even this can be corrected with a few deep inspirations before phrases. The outflow of air is so rapid that the expiratory drive does not disturb the player even if the inspiration is sometimes located high.

2. Players of the clarinet and bassoon, which require moderate airflow and only occasionally high pressure, prefer either an even or low location of inspiration. Though high pressure may disturb the circulation in pulmonary capillaries, this hardly happens during playing these instruments because of the accidental nature of high pressure phrases. However, the moderate

airflow may make the player feel that the expiratory drive disturbs his efforts to control the airflow. This happens if proprioceptor stimulation gets too strong due to an extremely high location of inspiration.

3. Players of winds requiring high pressure and minimum expenditure of air prefer a low location of inspiration. The oboe is the only instrument acting like this all the time. The blowing pressure is continuously so high that it seriously disturbs the pulmonary circulation. The only way to minimize the adverse effects is to locate the inspiration as low as possible. Because of the minimal airflow, proprioceptive stimulation has a strongly disturbing effect on the control of air flow. Thus there are two good reasons to concentrate on a low location of inspiration. Two players (who had two major instruments at the Department of Performing Arts at the Sibelius Academy) showed their natural inspiration before playing the oboe and the recorder in Figure 23. The difference between the locations of inspiration for the two instruments is obvious.

4. All brass instruments require either a very high or a very low pressure but almost continuously a high airflow. Players of these instruments prefer even and almost maximal inspiration. The high expenditure of air makes deep inspiration necessary. The pressure is high in the upper register. In the low register, all instruments in this group require a high expenditure of air and low blowing pressures. Therefore, a reasonable playing technique requires deep inspiration during which also the upper rib cage expands markedly.

Most of the present results on pressure and flow events during wind-instrument playing are parallel with those obtained by earlier investigators (Benade & Gans 1968; Bouhuys 1964; Roos 1936), with the exception that at that time Finnish oboists used to play with more pressure than their Mid-European and American colleagues. Individual playing habits may explain the difference in the blowing pressure to some degree. Also, according to American authors (Sprenkle and Ledet 1961), American reeds are lighter to play than French and German reeds. The Dutch oboists, investigated by Roos, have probably played with typical Dutch reeds which in the European tradition resemble most the American model (Ledet 1982), and which, therefore, demand less pressure. A lighter oboe sound was considered ideal during Stone's days (cf. Roos 1936), and the dynamics were more moderate in smaller orchestras. Therefore, high pressure was not needed even for stiff reeds.

6.3 Muscular activity

EMG recordings were included in this study to gain information about the type of muscular work involved in wind instrument playing and how it compares with the muscular work occurring during ordinary expulsive tasks.

The use of needle electrodes would have provided the most accurate method from a purely physiological point of view. However, this method had the disadvantage that the slight pain caused by the needles might have disturbed the performance of the players. Therefore, the natural choice was to use of surface electrodes. Though they measure larger area of muscular activity than needles, their application was warranted because the objective was to measure the activity of big muscle groups.

The use of relative scale was applied to analyse the results of the EMG-recordings. When surface electrodes were used the only reliable way to control the activity was to compare the level with the maximal effort of each muscle itself.

6.3.1 Breathing musculature working during playing

According to this investigation, most of the measured muscular activity during wind playing is done below the waist. When activity is recorded only in the proper breathing musculature above the waist (Bouhuys 1964; Berger 1968), the physical effort needed for wind-instrument playing appears smaller than it really is because there are no observation of the big abdominal musculature.

The functions of the abdominal muscles in breathing are 1. to stabilize the posture and shape of the abdominal and thoracic cavity so that it is ideal for respiratory function, 2. to aid ordinary breathing muscles in expiration and 3. to act as antagonists for the inspiratory muscles (Agostoni et al. 1960). The auxiliary inspiratory muscles, e.g. m. pectoralis, also participate in these processes.

6.3.2 Differences and similarities between musical performance and expulsive tasks

In all expulsive tasks, the subjects had an almost identical muscular recruiting order and similar activity levels though the tasks were performed voluntarily. The muscular activity during laughing and coughing was strong in the abdominal area. The specifity of these functions is reflected in the activity and recruiting order of muscle groups other than those recorded in this investigation: before laughing the laryngeal area is relaxed, but during laughing there is tension in the vocal chords. During wind-instrument playing the throat is supposed to be open.

The muscular activity in the abdominal area during sneezing resembles the activity during laughing and coughing. However, during sneezing the glottis is kept open. During spitting, the muscular activity differs from that of the above mentioned tasks: the glottis is kept wide open during the whole procedure, the facial musculature and the tongue have an active role in the performance, and the abdominal area is less activated than during coughing, laughing and sneezing.

6.3.3 Factors affecting muscular activity

The lung volume seems to be the most important factor determining the efficiency of muscular activity during pressure blowing: the smaller the lung volume, the stronger the muscular activity. Strong muscular activity is needed to produce a high pressure and weaker activity to produce lower pressures.

The role of muscle groups as agonists during wind-instrument playing and singing has been discussed by researchers (Berger & Hoshiko 1964; Berger 1968; Bouhuys et al. 1968). The gradually increasing activity in the trumpet player's muscles found by Berger and associates was interpreted as some kind of general agonism. When testing singers, Bouhuys and colleagues marvelled at the exactness with which they produced singing pressures at different lung volumes. Their study showed that during singing the diaphragm relaxed at the lung volume of 80 per cent of vital capacity. It was already known that pressures of about 3.0 kPa were often needed. This means that if a singer starts a performance after a deep inspiration, the necessary pressure is reached even if the respiratory musculature is absolutely relaxed. However, due to the pressure, the air starts to flow out immediately and the lung volume decreases. The result is that the airway pressure decreases too. When the lung volume decreases, increasing activity in the expiratory muscles is necessary to maintain steady pressure and to avoid failures in performance. If inspiratory activity is concurrently present, expiratory activity is also increased.

Agostoni and his associates (1960) studied the behaviour of the diaphragm in relation to transdiaphragmatic pressure. They noticed that activity can be recorded in the diaphragm at the very beginning of spontaneous expiration. This activity tends to disappear soon. The deeper the previous inspiration, the stronger the activity. The investigators explained this activity to be the result of a stretch reflex of the diaphragm, which is the stronger the more the thoracic cavity is expanded.

According to musicians and the results of this study (Chapter 2), the lower part of the thoracic cavity is more expanded during wind-instrument playing than during normal breathing. This means that the expiratory work of the lower intercostal and abdominal muscles occurs concurrently with diaphragmatic activity. Musicians may also voluntarily use this effect for practical reasons. When precise limb movements are needed, the role of the antagonist muscles becomes emphasized; their simultaneous and synchronized function is then necessary. This applies to the breathing musculature, too.

The recruiting order of the muscles tested in this study was not quite similar in all subjects. Most differences were found in the trapezial area. This is not very surprising because the trapezial muscle has various functions: it has an important role in maintaining posture, it supports the arms, and it also aids the proper breathing musculature. Along with other muscles, it was actively present during extreme efforts to produce a high airway pressure during wind playing.

The use of muscles during wind-instrument playing resembled their use during normal expulsive tasks and singing. Tone production with wind instruments and in the human vocal chords requires continuous air flow through the instrument or the larynx at a pressure which is higher than that during normal quiet breathing. Because most musical phrases are long, the inspiration before a musical performance has to be somewhat deeper than for a normal breathing cycle. At high lung volumes, the spontaneous pressure is, due to the elastic properties of the lungs, higher than needed for playing low-pressure winds and for soft singing. Unfortunately, low-pressure playing often requires a high expenditure of air, and therefore deep inspiration cannot be avoided. To keep the pressure low enough for musical purposes, the activity of the inspiratory muscles is needed until the lung volume has decreased to an adequate level of spontaneous pressure.

The most important inspiratory muscle, the diaphragm, relaxes immediately below the lung volume of 80% of vital capacity (Bouhuys et al. 1968). Activity is, therefore, needed in the other inspiratory muscles. The more the thoracic cavity can be expanded, the more effective the inspiratory effort. The most movable part of the chest is its lower part. Wind players' descriptions of their preparatory inspiration make sense: they tend to widen maximally the bottom of the thoracic cavity. If a very low pressure is necessary and a lot of air is needed, the upper parts of the chest cavity are also brought into use.

During a musical performance, the spontaneous pressure as well as the lung volume decrease. Steady pressure can be maintained either by decreasing the activity of inspiratory muscles or by increasing the expiratory effort. The other alternative is to keep these activities balanced so that the aimed pressure is reached all the time. There are many advantages in the latter approach. The most important advantage is perhaps the possibility to regulate the performance by two means: if there is a disturbance in one, the other is able to compensate for the failure.

The muscular work during the musical tasks resembled that occurring in the expulsive tasks: during sneezing the abdominal activity was nearly equal to that during singing or during high-register playing in forte. The breathing musculature was also activated equally during laughing and playing accented long notes.

The vocal cords act as the sound generator in singing. A certain tension is needed to make them vibrate when an adequate subglottic pressure is present. This is the natural function of the cords and it does not harm the vocal organs.

When we cough or laugh, the glottis is closed during some phase of the episode. If we imitate these expulsive tasks to find the correct abdominal activity for wind playing, we might use the glottis inadequately. When spitting or sneezing is imitated, this danger is avoided because the vocal chords are not involved. In many moderate wind-playing tasks, the abdominal activity resembles that occurring during singing. However, it would be dangerous to advise young wind players to imitate singing, because, with this technique, the vocal cords tend to become reflectively activated. In spitting, the airstream is strong, and even the position of the mouth closely resembles the embouchure when playing winds. The activity in the respiratory muscles is also similar to the activity during the performance of moderate musical tasks.

The task of pressure blowing revealed an important link between the lung volume and the behaviour of the breathing musculature. The non-musicians of this study inhaled during the pressure-blowing task as wind players do before playing. They were instructed how to inhale, not how to exhale. However, the muscular work during the blowing was very much similar to that of musicians during wind-instrument playing.

6.4 Intonation

The mouth tube could have been a real source of problems in the study of intonation failures. The pitch was, however, very steady in all experiments accepted by the players. When the pitch changed, the concomitant changes were so systematic that the disturbance caused by the tube could be considered negligible.

6.4.1 The effects of hearing loss on sensation of pitch

The acoustic and physiological conditions in which wind instrumentalists daily work are the source of several types of occupational hearing loss (Hart et al. 1987). Intraoral pressure, which is a prerequisite of wind-instrument playing, causes pressure changes in the middle ear. This may be a reason for the weakening of the pitch-discrimination ability among wind instrumentalists (Chadwick 1973). The placement of wind players in symphony orchestras is such that they are more vulnerable to hearing impairment than the other instrumental groups. As a result, their pitch-discrimination ability may also be impaired (Hart et al. 1987). Though this explains intonation failures in general, and the upward slides in particular, it does not account for the wind instrumentalists' tendency to slide downwards.

6.4.2 Embouchure and pitch control

The natural imbalance between the musculature which closes the mouth and that which opens it causes a tendency to raise the pitch (Porter 1967). Even healthy and highly trained musicians remember the pitch as being a little higher than it really was (Rakovski 1972).

The higher the tune is, the brighter the sensation (Colton 1987); the brighter the sensation, the higher the sensation of pitch (Wapnic et al. 1973). This explains the downward tendency in the high register.

6.4.3 The effects of respiratory mechanics

According to this investigation, players of the winds requiring a small expenditure of air fill their lungs up to about 75% of vital capacity (=VC). Those instrumentalists who expend more air inspire a little deeper, at least 80% of VC. The descending tendency of intonation correlates with the high airway pressure during playing. The compliance properties of the human lungs provide a possible explanation for slides of intonation. The wind players who inspire up to 75% of VC have a natural driving pressure of 1.5 kPa at the beginning of a tone. If more pressure is needed to hold the pitch, it must be produced with the work of the expiratory musculature. If less pressure is required, the inspiratory musculature is needed to reduce the pressure. When the lungs gradually start to empty, the natural driving pressure decreases too. Thus, a more active expiratory drive is needed to maintain steady pitch, otherwise the pressure will fall and the intonation drop (Benade & Gans 1968). The same mechanism explains the upward tendency for notes needing a low pressure. When the lungs are full of air, the expiration is preceded by a spontaneous pressure of about 3.0 kPa. Thus, at the beginning, the pressure is too high and inspiratory activity is needed to reduce it. When the air flows out, the spontaneous pressure decreases and less inspiratory activity is needed.

6.5 Oboe reeds

The tuning metres and reed making gauges used in this study to investigate the model and behaviour of the oboe reeds are similar to those generally used by teachers. Therefore, the present results can be applied to practical reed making.

Hypothetically, an ideal reed for beginners induces a minimal waste of energy, behaves logically with respect to intonation, and the timbre does not require manoeuvres with the lips. Although none of the reeds tested in this investigation fulfilled the criteria of the ideal reed, some of the reeds tested had characteristics that were close to the ideal.

When properly finished, artificial materials cause very little turbulent, thermal and viscous energy losses. The intonation problem, however, has to be overcome. Even the glass-fibre reeds had a pitch that behaved logically, though it was sharp. These reeds were extremely short. Perhaps it would be reasonable to make of this material reeds that are 3 - 5 mm longer and check the results.

Though the natural reeds were usually very stiff, there was one exception. This reed behaved quite logically with respect to blowing pressure and intonation. This reed was also exceptional in appearance: the long U-shaped scrape was finished with a faint W figure. By studying one good reed, it is not possible to discover a general method of making perfect reeds. However, this example proves that it is possible to make good light reeds of natural material too.

According to Ledet's investigation, excellent oboe players have made their careers by playing with greatly varying reeds. In earlier studies, the pressure needed for oboe playing was not found to be so extremely high as for the reeds investigated in this study. Perhaps Finnish reeds which are very much alike make oboists play with similar pressures. However, it might be worth trying to construct and test different types of reeds to find lighter natural reeds, at least for pedagogical purposes.

Impregnation of reeds with polymer (Locker et al. 1981) could offer an alternative between artificial and natural reeds. The blades of the reed could be modelled from natural material but the impregnated polymer would make the reed more water repellent, and the inside of the reed blades would be smoother and thus the energy loss smaller.

In order to develop better reeds, either of natural or artificial materials, more detailed investigations of acoustic and mechanical properties of reeds are necessary. The reeds should be as perfect as possible in all aspects of intonation, energy need, and timbre. They should also be tested with a great variation of human embouchure.

6.6 Adaptation

The abnormal ratios in the Valsalva test show that adaptive circulatory changes, associated with playing, happen in wind instrumentalists. So many of them could have not been noticed without additive advice to the ordinary measuring equipment.

The belts measuring chest movements, designed for this investigation, are a valid instrument when placed adequately. They are reliable in locating the area used in respiration. The location of respiration is determined by comparing the stretching of the belts in different places on the thorax. Some normal respiratory phase is used as the control position for the measurements. During the present experiments, the belts were closed at the RFC-level. Accurate estimations of volume changes cannot be made with the belts, however. Therefore, normal spirometry was carried out when comparing tidal volumes and respiratory frequencies of the wind players and control subjects. Instead, in retrospect, if the belts had been used during the Valsalva-tests they would have verified the evident explanation given to the unexpected result.

6.6.1 Changes to normal breathing

Most urban people do not need very deep breathing during their everyday duties which, due to modern technology, do not demand much physical effort.
Therefore, at the beginning of wind-instrument studies, one of the most difficult tasks is to increase inspiration just before playing. The success is immediate when one learns to relax the stomach. Because this type of breathing, once learned, requires less physical effort and is thus perhaps more natural, players are inclined to adopt it for general use.

When breathing is deep, it is necessary to decrease the respiratory frequency to keep minute ventilation at an adequate level to prevent too high wash-out of carbon dioxide.

6.6.2 Breathing patterns before playing

The changes in the breathing pattern just before playing have at least three functions: to ensure that there is enough air for a long phrase, to minimize disturbance in the respiratory control, and to prevent failure in circulation due to respiration.

Some players increased the respiratory frequency during the 30-second period preceding the playing of a long note. By doing so, the player perhaps tries to prepare the organism for the lack of ventilation by minor hyperventilation before the performance. The FRC-level increased in many players. It is possible that the motor control of the respiratory musculature is easier when there is no sudden increase in the respiratory volume just after a normal tidal volume and before an exceptionally slow expiration.

6.6.3 Subnormal ratios in Valsalva tests

During inspiration, pulmonary capillaries and alveoles open and the lungs are filled with air and blood. Therefore, one deep breath just before either the Valsalva test or playing a high-pressure note disturbs the venous return less than if the test or playing is started without extra storage of blood in pulmonary capillaries. The gradual increase of the FRC-level, while the expiratory volume stays constant, may have the same or perhaps even a stronger effect.

The effects of breathing on blood circulation just before playing might explain the players' small Valsalva ratios and the delays in the Valsalva phases. Such compensatory systems may also explain why musicians are able to play extremely long phrases without fainting.

6.7 Occupational implications

The symptoms which the players regarded as consequences of stage fright were typical of sympathetic activity. Respiratory failures, and weakness were the prominent symptoms among the wind players, while the other musicians most often suffered from tremor. The airway pressure during wind-instrument playing is often higher than the pressure levels used in the Valsalva test. Therefore, the reactions of the autonomic nervous system may result from pressure strain. The first symptom may be a feeling of weakness which can be followed by a gray- or black-out.

Beta-blocking agents were often used as medication for the symptoms of stage fright. Their efficiency is based on their ability to block the sympathetic activity which is present during physical and mental strain. Parasympathetic activity is prominent during rest. If this autonomic activity decreases, the consequences are similar to those caused by increased sympathetic activity. The increase in the heart rate resulting from decreasing parasympathetic activity cannot be completely prevented with beta-blocking medication (Nies 1986). It is not necessarily wise to try to prevent palpitation by means of medication. Because, during wind-instrument playing, as during the Valsalva test, increased heart rate is a prominent and important reaction in the regulation of blood pressure (Piha 1989).

7 IMPLICATIONS FOR PEDAGOGY

7.1 Teaching breathing technique

7.1.1 Breathing pattern during wind-instrument playing

Knowledge about the physiology of respiration is necessary in the search for an adequate method to teach breathing for musical purposes. The present study offers a description of the breathing associated with wind playing.

A preparatory phase of breathing precedes playing. The tidal volume (= TV) may increase during some respiratory cycles, just before playing, to the volume at which the playing is started. Alternatively, the tidal volume may remain at the level which is the same as during quiet breathing but the end-expiratory volume increases. The resulting preparatory inspiration is then: the end-expiratory volume + unchanged TV.

The preparatory inspiration begins with diaphragmatic activity. The muscles descend and increase the space of the thoracic cavity. The abdominal organs are pushed down- and sidewards. The abdomen expands and the lowest external intercostal muscles pull the rib-case outwards. The belts measuring chest movements can be useful when demonstrating the procedure to the pupils. The space in the lower thoracic cavity increases. The belt which is closed at the FRC-level over the lowest part of the rib-case opens. To reach an adequate inspiratory level before playing, also the upper rib-case is expanded. There are differences among instruments, so that when playing winds needing only a small amount of air, the upper parts of the rib-case are expanded less than when playing winds demanding a larger expenditure of air. The upper belt opens when the upper external intercostals and the pectoral muscle become activated. In most cases, the upper belt is less stretched than the lower.

The abdominal musculature is activated at the start of blowing, most often the external oblique first. The diaphragm is gradually relaxed (Bouhuys 1968) in order to transmit the abdominal pressure of the thoracic cavity. At the beginning of playing the belts stay almost unchanged.

When air flows out, the respiratory volume decreases, and to maintain an unchanged flow and pressure, the abdominal pressure has to be increased by increasing the activity of the abdominal musculature. Soon the diaphragm is completely relaxed, in singers when as much as 80% of vital capacity is left (Bouhuys 1968). The deflation of the thoracic cavity can be seen as a gradual closing of the lower belt. The upper belt stays in its starting position.

At the end of an extremely long phase of playing, the work of the abdominal musculature is very strong. Obviously at least the lower internal intercostal muscles pull the rib-case inwards because the lower belt is closed. The activity of the pectoral muscle increases in order to prevent the upper parts of the rib-case from deflating and, in that way, ensuring the continuation of pressure and flow as long as possible.

7.1.2 Belts measuring chest movements as an aid in teaching

Players are advised to check, with their hands above the waist, the widening of the rib-case to control the preparatory inspiration (Hilton 1951; Rothwell 1968). This method has been adopted from singers. It is possible to do the same test with the belts measuring chest movements. With the belts, however, one has the advantage of observing their behaviour from a mirror even during playing. When inspiration has been learned well enough, long notes can be practised by taking care that the belt stretches as expected.

The reasonable direction of breathing between musical phrases can be determined on the basis of the stretching of the belts. If the belts have closed only slightly when the breathing pause is reached, it is reasonable to expire a little, go on playing and inspire at the next breathing pause. Intermittent breathing, which is recommended both by oboe schools and pedagogical books (Hilton 1951; Rothwell 1968; Tolksdorf & Rösler 1978; Thomas 1981), is difficult to control and study without sufficient demonstration appliances. Therefore, intermittent breathing can usually be learned only during the later stage of studies.

Circular breathing is a technique which wind players have adopted from glass blowing. Continuous, seemingly endless expiration is produced in the following way. Cheeks are filled with air, the tongue separates the mouth cavity from the other airways and continuous blowing is maintained with the assistance of the cheeks and tongue while inspiring at the same time through the nose.

Relaxation of the abdominal musculature is necessary before starting circular breathing. Achievement of a correct image of the process has been described to be the most difficult part of the method (Thomas 1981). Rapid relaxation from the ordinary playing situation and subsequent reactivation may be easier when visualized with the belts.

7.1.3 Recognizing faulty breathing

To deal adequately with pupils having problems with intonation, articulation, or controlling nuances, teachers should be able to recognize whether the difficulties result from faulty breathing or embouchure. However, reliable means for solving these problems could not be described by the teachers interviewed for this study.

If the control of sound is lacking when playing without lip pressure, the fault is almost certainly in the breathing technique. If the preparatory inspiration is adequate and the expiratory phases during playing seem to be timed and located as expected, when controlled e.g. with the belts measuring chest movements, the source of failure can be between the lungs and the embouchure, in the player's throat.

When tension in the vocal cords hinders the thoracic pressure to become transmitted into the mouth cavity, blowing energy is wasted. This loss must be compensated for by increasing the expiratory effort. The strain during playing is then increased excessively. Fink (1980) describes in his book "The Trombonist's Handbook" a similar chain of events, though in the opposite direction: when a player blows too much, he begins to control airflow with vocal tension. The result is the same in the both cases. The vocal cords will be damaged.

Some singers are convinced that wind playing destroys their vocal cords (Gossett 1989). The consequences of playing winds with tensed vocal cords may be the reason for their negative attitudes. Playing with tensed vocal cords is, however, as disastrous to wind players as it is to singers. Players do not notice the harmful effects as quickly as singers who very quickly lose their ability to work at all.

Just as a wrong playing technique may cause difficulties in vocalization, faulty speech habits may cause problems in wind playing. As during speech, habitual vocal tension may also occur unconsciously during playing. A teacher may recognize the situation by identifying the symptoms associated with vocalization problems (Aalto & Parviainen 1985) which make the voice sound hoarse, lowered, weak, weird, too strong, creaky, shrill, or thin.

The player himself should try to control his breathing more efficiently if he has the following feelings during playing (Aalto & Parviainen 1985): throat is dry, throat is sore, pharynx is parched, sensation of bolus in the throat, irritation to cough, blowing tends to end too early, or a feeling of having a collar around the neck. Wind players, as well as speakers, may get help from vocal therapy. The Alexander technique is commonly used to treat in these problems, too (Gelb 1994).

7.2 Correcting intonation

The basic source of correct pitch in wind instrument playing, an adequate blowing pressure, can not be visualized. Therefore, the main reason for intonation problems can never be identified with absolute certainty. However, the problem has to be identified in order to find a valid method for its correction. The results of this investigation offer an explanation additional to those already known by wind teachers(Chapters 5.4 and 6.4).

Many methods based on generally accepted principles to improve intonation have been introduced in literature. Evelyn Rothwell (1968) and Arthur Weisberg (1975), among others, have described in detail the most important rule applying to intonation: the tighter the embouchure and the higher the pressure or flow, the sharper the pitch, and vice versa.

Fanatical opinions condemning the use of the embouchure in the regulation of intonation and dynamics have sometimes been expressed. According to this view, only the regulation of pressure and flow is accepted, and thus the blowing technique alone is responsible for intonation.

When different reeds were tested in this study, the blowing pressure was found to be so high that playing the upper register was impossible without lip pressure. At least for the correction of small failures in intonation, some teachers recommend the use of the embouchure (Fitch 1953). Also, checking the depth of the reed in the mouth has been suggested (Fitch 1953; Reimer 1957; Rothwell 1968; Tolksdorf and Rösler 1978). The position of the tongue in the mouth has also been claimed to be of some importance in the regulation of intonation (Reimer 1957; Leonard 1960). The use of the embouchure can be supported by the fact that only the small mimical musculature is rapid enough to follow satisfactorily the needs of musical performance. If the breathing technique is not well practised, it is not possible to use the embouchure properly. If the embouchure is too elastic, there is the danger that the control of breathing becomes lazy.

If we want to use the embouchure in the regulation of intonation, we must take care that the breathing technique is natural and under control. Failures in sound production do not, however, always reveal whether the weakness is in the embouchure or blowing. Because practising the embouchure cannot be controlled without sound, blowing is needed. Blowing can be controlled, however, without the embouchure, using the tube introduced in the reed experiments of the present study. If intonation, dynamics and timbre are difficult to control with normal technique but possible to keep steady for a while when using the tube, the problem is most probably with the embouchure. If problems occur even when using the tube, it is necessary to improve the blowing technique before reliable results can be expected in the use of the embouchure.

The results of the present study (Chapters 5.4 and 6.4) demonstrate that the slides in intonation by professionals, who have a good control of their embouchure, result from an insufficient increase in the blowing strength when the lungs become empty. It is not possible to hear very small changes in intonation without a control tone (Rakowsky 1971). When playing alone, small slides are acceptable. However, after a few weeks of regular practising this may become a habit which is difficult to break. When playing together with other musicians, the slides become evident when contrasted with slides in the opposite direction.

A good blowing technique is based on good control of breathing. Problems arise when two players tending to slide in the same direction try to control intonation by playing in unison. Since both players have the same tendency, parallel slides help to maintain common intonation. However, it does not prevent the dangerous minimal slides. Instead, it rather supports their occurrence. To avoid the danger of supporting common faults, it is wise to practise intonation by playing together with an instrumentalist whose instrument is less prone to sliding. The danger of anchoring the sensation of pitch to timbre - bright is heard sharper than dark (Wapnic & Freeman 1973) - can be avoided by playing in mixed instrumental combinations. Fitch (1962) suggests such combinations as oboists and flautists, or oboists and clarinettists. String players, with their steady long notes, can be good partners as well. Playing long notes temporarily with a tuning meter supports the same aim.

7.3 Practice

According to Evelyn Rothwell's (1968) definition, the aim of practice is: "to gain the perfect muscular coordination and control (which is needed for playing) by means of conscious and concentrated spiritual discipline without accepting a single, least slip or mistake". Good results can only be gained if one practises when alert and in good physical condition. Therefore, Rothwell advises splitting the daily practice sessions into short periods.

7.3.1 Motor coordination

The muscles working concurrently during wind-instrument playing differ in shape and type. The present study demonstrates that for exact articulation, discrete simultaneous work is needed in the small, rapid mimical muscles and in the big, clumsy postural muscles (Chapter 5.3.1). The task of the fingers is relatively simple as compared with that required in piano or violin playing, for instance. However, finger exercises usually constitute the most important part of motor training in woodwind playing.

Because the work of all muscles involved in playing must be synchronized before the training of a musical piece is completed, the slow practice tempo suggested by Rothwell makes sense. However, slowing down the original tempo may be problematic because the composer has often planned the breathing pauses to secure the best possible conditions for the final tempo. Thus, playing some musical phrases in a slower tempo can cause inconvenience, and it may be impossible without some extra breathing pauses.

7.3.2 Slow practice in wind playing

Because the performance of the breathing musculature must be coordinated with the other muscular work involved in playing, it is necessary to use regularly the breathing pauses planned for the final tempo. Since practising long units in a slow tempo is not possible, the piece must be broken into sections which can be reasonably practised. The smallest possible section is then a phrase between two breathing pauses.

Another possibility to practise slowly is to break down the motor training into different levels: fingers are first practised without sound so that large units become automatically mastered by the hands, and then the practice continues aloud in tempo with a conscious control of breathing.

No attention is paid to the musculature of the embouchure in this two-fold practice method. Therefore, it is wise to make a combination of these practising methods: to start working on a musical piece by playing slowly one phrase at a time and have a good rest between the musical units - attention is mainly paid to breathing and the embouchure - then training continues by the "two-fold method" which could be the frame of practice.

7.3.3 Daily practice

Wind-instrument teachers warn almost unanimously of stereotypical practising because routine is thought to result in diminished concentration. Inexactness may lead to a systematic practice of mistakes. The fear of establishing routines may also be a reason for the lack of advice concerning oboists' warm-up routines before playing even in the pedagogical literature. Brass players regard warm-up exercises as a natural and important part of their daily work (Fink 1980; Fox 1974; Johnson 1986). Their goal is the same as that of athletes' warm-up training. However, oboe playing causes changes in circulation which are at least as obvious as those occurring during sports, though different in nature. Therefore, it could be advisable to adapt oneself to the playing conditions, especially to high airway pressure, by "spitting" single tones, one at a time in scale studies, making a tiny pause after each note. The musculature involved is then allowed to act together at the correct relative strength. During periods of rest, circulation increases in the muscles and they are therefore better prepared for the stress of playing.

Though it may not be wise to have always the same practising routine, there are some exceptions. According to sport physiologists, it is necessary to repeat motor models at least five days a week until the task is mastered. To maintain the skill, it is enough to practise three days a week. The same rule also applies to music teaching.

Playing technique is usually easiest to observe by listening to a pupil playing. By doing so, it is easy to decide when a specific skill only needs maintenance practice and when to take time for learning a new motor model. This study offered some hints about the physical adaptation occurring in wind playing. This adaptation is, however, difficult to observe. It is not known how many months or years a pupil must play before he gains a sufficient playing endurance. Probably, one should carry on practising regularly until the best possible endurance is reached. In real life this is not possible for most pupils. It is, however, good to remember that the more strictly this practice schedule is adhered to, the sooner the physiological prerequisites are met with and the player can start demonstrating his skills as a musician.

7.4 Teachers' responsibility

Some beginners may quit playing because of the unpleasant sensations related to wind playing. It is possible that professional wind instrumentalists are tougher than ordinary music enthusiasts. Therefore, teachers should pay serious attention to the stress related to playing an instrument. Pupils are not necessarily lazy when they complain that they do not feel well. The pupil has probably not had enough time to get adapted to the stress associated with the task on hand. Though the task may have been successfully performed during the previous lessons, it perhaps demanded such an extreme effort that the pupil is not able to reproduce it due to fatigue.

Playing, like any physical work, causes tiredness. Pain and not feeling well are, however, always a warning. A teacher who leads his pupils to believe that pain is a natural feeling associated with playing is acting irresponsibly. Investigations, made among pupils, verify that even very young children have been convinced that physical suffering is an important part of learning to playing a musical instrument (Fry et al. 1988; Lockwood 1988). In this way, the teacher does not give the pupil the opportunity to develop for himself the most suitable and ergonomic way of playing.

7.4.1 Methods suitable for teaching wind playing

The general methods of music education make no distinction among instruments. Early sight reading and singing skills, which are essential elements of the Kodaly method , are of great help both for pianists and wind players (Landis & Carder 1972). Though the Suzuki method (Winberg 1980) is widely spread and is being developed to cover an increasing number of instruments, the winds are seldom taught as Suzuki instruments.

There are good reasons not to begin wind playing, other than the recorder, at an early age in spite of some fashionable methodological arguments. It is possible to produce high airway pressure at any age for a short time, for instance during coughing. However, the control of air flow and pressure for musical purposes does not necessarily succeed with the same mechanism in child- and adulthood. In children, the respiratory control depends on proprioceptor stimuli even at the tidal volume level, while in adults the stretch stimuli become important only at high respiratory volumes (West 1983). Young players of any wind instrument should therefore be prepared to change their blowing technique, perhaps in a radical way, after a few years of studies.

7.4.2 Playing when ill

If a teacher has had the patience not to lead his pupils to believe that suffering is the only way to mastery, he can rely on the pupils' own feelings about their physical capacity for playing. The problems related to the physiology of wind playing concern such a small group of people in Finland and can be so specific, as demonstrated in present work, that they might not be known to all physicians. For instance, the wind musician is expected to recover from a surgical operation and resume work as quickly as a person who works with a computer. However, according to the present results (Chapter 5.3), the muscular activity during wind-instrument playing is often maximal, comparable to that during heavy physical work. Therefore, an oboe or bassoon teacher who takes a pupil's instrument "to be repaired" after the pupil has had an operation in the abdominal area, or starts a reed-making period for a few weeks instead of normal lessons, does not make a pedagogical mistake but reveals his responsibility as a professional.

The nature of wind playing should always be taken into consideration when dealing with different illnesses. For instance, if a wind player undergoes an orofacial operation, he needs a vacation from playing to avoid the risk of bleeding. Extremely high mouth pressures may lead to an uneven distribution of circulation and therefore, the blood pressure may change unexpectedly. Dentists should therefore know about hobbies like wind playing so that they could estimate patients' ability to resume playing after the removal of a wisdom tooth, for example.

7.5. Physiology as an accessory in wind-instrument pedagogics

Arnold Jacobs, a tuba player from Chicago, first studied human physiology as a hobby, and later also as an aid for teaching. He reasoned on behalf of the usefulness of physiological knowledge for players (Frederiksen 1996): "Just as most motorists know little or nothing about the mechanics of their car, most musicians know little or nothing about the mechanics of breathing. For general driving of a car a knowledge what is happening under the hood is not required. However, for more serious driving, such as racing, the more detailed understanding of the car´s mechanics would be helpful. The same is true in understanding the mechanics of breathing." Jacobs names the tuba and the oboe as the most extreme instruments as far as breathing is concerned. To those, who speak about "normal breathing" during playing he reminds:" Breathing to play an instrument is clearly different from breathing to live. Mechanical wind is needed to produce sound rather than chemical exchange needed to produce homeostasis".

The more a teacher knows about the physiology of playing, the better he can coach a pupil to cope with the physical efforts of playing. However, a good coach is not necessarily a good teacher. If the musical goal of playing is forgotten or is secondary to technical skills, even the most excellent breathing technique and muscular coordination do not serve their proper purpose.

The manner in which a teacher applies his knowledge is a good criterion of his pedagogical skills. When a pupil tries to concentrate on music, it is not wise to disturb him by describing what is happening or should happen in the human body, because then the pupil may start watching his body instead of listening to playing.

Encouraging musical motivation is the only honest way to teach playing a musical instrument. Correctly applied physiological knowledge may help a teacher to alternate between new challenges and sensations of success so that the best possible motivation is reached. Well chosen verbal images which can be associated with physiological events of playing help the pupil find a playing technique which suits him best. Then it is not necessary to use any physiological terminology during the lesson.

Physiological knowledge can be best applied by planning systematic long-term schedules of studies. An important part of this task is to develop a fair way of measuring the results of learning. The soloistic examinations should not be, for any instrument, an endurance test. They should for all students be an official opportunity to show their artistic goals and skills.

SUMMARY

This study concentrated on the essential aspects of the physiology of wind-instrument playing, breathing and its consequences. Matters of interest were also the nature of the physiological knowledge that Finnish wind teachers had about playing and their attitudes about the role of physiology in music pedagogy.

Altogether 51 wind teachers were interviewed to gather the latter information. The teachers considered proper breathing to be the basis of a good playing technique. The meaning of the term physiology was not familiar to some of the teachers: instead of associating it with all aspects of bodily functions, they rather used the term as a synonym for either anatomy or pathology. Physiological knowledge was considered to be especially valuable in elementary grade teaching.

Physiological methods were applied to study some aspects of the breathing associated with playing different winds. These included expenditure of air, blowing pressure, lung volumes at the beginning of playing, and the location of breathing.

Traditional spirometry, intra oral pressure measurement, and belts measuring chest movements were the methods used for mapping the breathing patterns associated with wind playing. Professional orchestra players (26) and students (37) majoring in winds at the Sibelius Academy were the subjects in this investigation. On the basis of the results, orchestral winds can be divided into four groups according to their physical demands: 1. low-pressure winds with moderate or high expenditure of air; 2. winds which occasionally demand high pressure but which most of the time, especially in the mid register and moderate dynamics, require moderate pressure and expenditure of air; 3. high-pressure winds with minimum expenditure of air; 4. instruments which require high pressure in the high register and low pressure in the low register but varying expenditure of air, most of the time high or moderate. The preparatory inspiration was found to be located in the groups as follows: 1. even or high location; 2. even or low location; 3. low location 4. low or even location, often nearly full capacity.

EMG recordings were included in this investigation to get information about the type of muscular work involved in wind-instrument playing and singing, and how it compared with the muscular work occurring during ordinary expulsive

tasks. Ten professional wind-instrument players, six singers, and six subjects without any experience in wind playing and singing participated in this investigation.

The results show that most of the muscular activity measured during wind playing took place below the waist. The use of muscles during wind-instrument playing resembled their use during normal expulsive tasks and singing. The non-musicians of this study inhaled during the pressure blowing task as wind players do before playing. Although, they were not instructed how to exhale, their muscular work during the blowing was very much similar to that of musicians during wind-instrument playing.

Intonation inaccuracy under the physical strain associated with wind-instrument playing was determined by measuring the changes in intonation, dynamics, and airway pressure occurring during playing. Twenty-five professional musicians participated in the experiments.

Failures in intonation were small. The biased tones tended to slide to the direction, where the physical effort needed was smallest. If the pressure required was lower than the pressure during spontaneous expiration, the tone tended to get sharper, if the needed pressure was higher than the spontaneous pressure, the tone tended to get flatter.

Because the goal of reed making for beginning oboists is to construct light reeds with good intonation, electromechanical methods were used to determine the intonation and blowing-pressure demands of reeds made of natural and artificial cane. Sixteen reeds were measured, ten natural reeds hand made by teachers, and six commercial reeds made of artificial material, three from plastic and three from fibre-glass.

Artificial reeds were lighter to blow but had more troublesome intonation than most natural reeds. However, one natural reed was almost as light to blow as those lightest artificial reeds, and it had the most logically behaving intonation of all reeds measured in this investigation.

To find out whether wind-instrument playing resulted in adaptation to the respiratory and circulatory strain associated with the playing, measurements were conducted in 33 student wind-instrumentalists and seven experienced orchestral wind players. The two control groups consisted of 32 medical students and 14 beginners in wind playing before their first lesson.

Wind students' inspiration preparatory to playing, and the tidal volume of both both from wind players and controls were measured with normal spirometry. The beginners' inspiration before pressure blowing was controlled with the belts measuring chest movements. The experienced professionals' circulatory reactions to pressure strain were investigated with the Valsalva test. A typical change in the preparatory inspiration before playing was observed in almost all music students. No such breathing was found in the beginners before pressure blowing. A large tidal volume and a low respiratory rate were more common among music students than medical students. Compared with the age-related reference values Valsalva ratio was lower and the delay longer in all professional subjects. The changed Valsalva ratio of the professional players is probably a circulatory adaptation to the high pressure playing.

A questionary regarding subjective experiences of occupational health hazards was sent to all professional orchestral musicians in Helsinki. 115 players answered the questions. According to the answers, wind players do not suffer more than other players from circulatory or respiratory diseases.

YHTEENVETO

Tässä työssä selvitettiin oleellisinta puhallinsoiton fysiologiaa, hengitystä ja siihen liittyviä tekijöitä. Opettajien soittoon liittyvän fysiologian tietoutta ja heidän mielipiteitään tiedon tarpeellisuudesta selvitettiin haastattelulla. Kaikkiaan 51 puhallinopettajaa haastateltiin. Opettajat pitivät hyvää hengitystä hyvän puhallinsoittotekniikan perustana. Termi fysiologia ei ollut joillekin opettajille tuttu, vaan he pitivät sitä lähinnä termien anatomia ja patologia synonyymina, Fysiologista tietoa pidettiin erityisen arvokkaana alkeisopetuksessa.

Soittoon liittyvää hengitystä tutkittiin perinteisellä spirometrialla, hengitystiepaineita mitattiin suun sisäisesti mittariin kytketyn ohuen teflonletkun avulla ja hengityksen sijoittumista tarkoitukseen konstruoitujen vöitten avulla. Tutkimukseen osallistui koehenkilöinä 26 ammattiorkesterien puhaltajaa ja 37 Sibelius-Akatemian pääaineellista puhallinsoiton opiskelijaa. Saatujen tulosten perusteella voidaan sinfoniaorkesterin puhaltajat jakaa neljään ryhmään soitinten äänentuottoon tarvittavan ilmatiepaineen ja ilman kulutuksen mukaan: 1. matalapaineiset ja vain kohtuullista painetta vaativat soittimet; 2, puhaltimet, joissa satunnaisesti tarvitaan korkeaa painetta, mutta jotka enimmäkseen, varsinkin keskirekisterissä ja kohtuullisella dynamiikalla soitettaessa vaativat vain kohtuullista painetta ja virtausta; 3. korkeapaineiset puhaltimet, joissa ilman virtaus on lähes olematon; 4. ylärekisterissä korkeapaineiset ja alarekisterissä matalapaineiset puhaltimet, joissa virtauksen määrä vaihtelee, yleensä suuresta kohtuulliseen. Näiden ryhmien kesken hengityksen sijoittuminen jakautui seuraavasti; 1. tasainen tai korkea sijoitus; 2. tasainen tai matala sijoitus; 3. matala sijoitus; 4. matala tai tasainen sijoitus ja usein erittäin syvä soittoon valmistava hengitys.

EMG-rekisteröinnein tutkittiin soittoon liittyvää lihastyötä ja sen yhtäläisyyksiä ja eroja lauluun, painepuhallukseen ja keuhkoja puhdistaviin refleksisiin toimintoihin liittyvän lihastyön kanssa. Koehenkilöinä oli kymmenen ammattipuhaltajaa, kuusi laulajaa sekä kuusi verrokkia, jotka eivät olleet harrastaneet laulua eivätkä puhallinsoittoa. Tuloksista selvisi, että enimmillään soiton aikana oli lihasaktiivisuutta vyötärön alapuolella. Lihasten käyttö oli varsin samanlaista sekä puhallinsoiton että laulun ja keuhkojen puhdisturefleksien aikaisen lihastyön kanssa. Kun painepuhallustehtäviin verrokkeja opastettiin valmistautumaan samanlaisella sisäänhengityksellä kuin oli ammattimuusikoiden lauluun ja soittoon valmistava hengitys, lihastyö oli samanlaista kuin laulun ja soiton aikainen lihasaktiivisuus.

Soittoon liittyvän rasituksen vaikutusta puhaltajien intonaatioon selvitettiin hengitystiepaineen, intonaation ja dynamiikan yhtaikaismittauksin. Koehenkilöinä oli 25 ammattipuhaltajaa. Virityspoikkeamat olivat vähäisiä. Niiden suunta oli rasitukselta säästävä: viritys liukui ylöspäin jos äänen edellyttämä paine oli pienempi kuin spontaani uloshengityspaine ja alaspäin kun soittopaine oli suurempi kuin spontaani uloshengityspaine.

Vasta-alkaville oboisteille pyritään tekemään niin keveitä röörejä kuin intonaatiota tuhoamatta on mahdollista. Tässä tutkimuksessa verrattiin keinoaineisten ja ruokoröörien intonaatio- ja paineominaisuuksia oppilasrööreille asetettujen vaatimusten kannalta. Kuusitoista rööriä mitattiin. Niistä kymmenen oli opettajien valmistamia ruokoröörejä, kuusi keinoaineisia valmisröörejä, kolme muovista ja kolme lasikuituista. Keinoröörit olivat keveämpiä puhaltaa, mutta intonaatioltaan huonompia kuin useimmat ruokoröörit. Yksi ruokorööri poikkesi säännöstä. Siinä oli paras intonaatio kaikista rööreistä ja se oli melkein yhtä kevyt puhaltaa kuin keveimmät keinoaineröörit.

Puhallinsoittoon adaptoitumista tutkittiin mittaamalla muutoksia lepohengityksessä ja soittoa edeltävässä hengityksessä 33 puhallinopiskelijalta sekä verrokkeina lepohengitystä 32 lääketieteen opiskelijalta ja painepuhallusta edeltävää hengitystä 14 aloittelevalta puhaltajalta ennen ensimmäistä oppituntia. Menetelminä olivat perinteiset spirometriamittaukset ja rintakehän venymisen seuraaminen mittavöiden avulla. Seitsemän kokeneen ammattipuhaltajan verenkierron säätelyä testattiin Valsalvan kokeen avulla, ja tuloksia verrattiin ikään suhteutettuihin viitearvoihin. Hidas hengitysrytmi ja suuri kertahengitystilavuus oli tavallisempi puhaltajilla kuin verrokeilla. Soittoa edeltävä hengitysmalli muuttui painerasitukselta säästävällä tavalla puhaltajilla. Verrokeilla ei vastaavaa hengitysmuutosta havaittu ennen painepuhallusta. Ammattipuhaltajien Valsalvan kokeet poikkesivat viitearvoista: suhde oli normaaliarvoja pienempi ja Valsalvan viive pidempi kuin normaaliarvot edellyttivät. Muutokset ovat oletettavasti merkkejä soittorasitukseen adaptoitumisesta.

Helsinkiläisille orkesterimuusikoille lähetettiin kysely, jolla oli tarkoitus selvittää millaisista muusikon ammatista johtuvista hyvinvointiongelmista he kärsivät. 115 soittajaa vastasi kyselyyn. Näiden vastausten perusteella puhaltajat eivät näytä kärsivän muita muusikoita enemmän hengitys- ja verenkiertoelinten sairauksista.

REFERENCES

Aalto, A.-L. & Parviainen, K. 1985. Auta ääntäsi. Keuruu: Otava.

Agostoni, E, Sant'ambrogio, G & del Portillo Carrasco, H 1960. Electromyography of the diaphragm in man and transdiaphragmatic pressure. Journal of applied physiology 15, 1093-1097.

Barret, A. M. R. 1986. Méthode complete de hautbois 1-3. Paris: Leduc.

Bate, Ph. 1954. Oboe in Grove's Dictionary of Music and Musicians (5th ed.): Vol. 6. Hong Kong: Macmillan.

Bate, Ph. 1975. The Oboe. London: Ernest Benn

Benade, A. H. & Gans, C. J. 1968. Sound production in wind instruments. Annals of the New York Academy of Sciences 155, 247-263.

Berger, K. 1968. Electromyographic recording during wind instrument performance. Annals of the New York Academy of Sciences 155, 297-302.

Berger, K. & Hoshiko, M. S. 1964. Respiratory muscle action of trumpet players. The Instrumentalist 19 (Oct.), 91-94.

Bouhuys, A. 1964. Lung volumes and breathing patterns in wind instrument players. Journal of applied physiology 19, 967.

Bouhuys, A. 1968. Pressure-flow events during wind instrument playing. Annals of the New York Academy of Sciences 155, 264-275.

Bouhuys, A., Mead, J., Proctor, D. F. & Stevens, K. N. 1968. Pressure flow events during singing. Annals of the New York Academy of Sciences 155, 165-176.

Brod, H. 1951. Études et sonates pour hautbois. Paris: Leduc.

Chadwick, D. L. 1973. Music and hearing. Proceedings of the Royal Society of Medicine 66 (Nov.), 1078-1082.

Cohen, M. I. 1970. How respiratory rhythm originates: evidence of discharge pattern of brainstem respiratory neurons. In Breathing. Hering - Breuer centennary symposium. London: J & A Churchill, 125-157.

Colton, R. H. 1987. The role of pitch in the discrimination of voice quality. Journal of voice 1 (3), 240-245.

Dahl, M. G. C. 1978. Flautist's chin, a companion to fiddlers neck. British medical journal 7 (Oct.), 1023.
Davies, J. & Harris, P. 1990. 80 graded studies for oboe. London: Faber.
Dawson, W. J. 1986. Reed-maker's elbow. Medical problems of performing artists 1 (March), 24.
Debondue, A. s.a. Vingt-cinq études-déchiffrages. Paris: Leduc.
Faulkner, M. & Sharpey-Schafer, E. P. 1959. Circulatory effects of trumpet playing. British medical journal 14;1(5123), 685-6.
Ferling, W. s.a. 48 Études op. 31. Paris: Billaudot.
Flemming, F. 1929. 60 Übungstücke für Oboe. S.l.: Zimmermann.
Fink, R. H. 1980. The trombonist's handbook: a complete guide to playing and teaching the trombone. Athens (USA): Accura Music.
Fitch, W.D. 1953. Practical guidance for student oboists. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1953, Oct.), 440-441.
Fitch, W. D. 1962. Transfer to oboe. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1962, Dec.), 455-456.
Fox, F. 1974. Essentials of brass playing.Los Angeles: Fox.
Frederiksen, B. 1996. Arnold Jacobs. S.l.: WindSong Press.
Fry, H. J. 1986. Incidence of overuse syndrome in the symphony orchestra. Medical problems of performing artists 1 (Dec.), 54-55.
Fry, H. J., Ross, P. & Rutherford, M. 1988. Music-related overuse in secondary schools. Medical problems of performing artists 3 (Dec.), 133-134.
Gärtner, J. 1981. The Vibrato.Regensburg: Gustav Bosse.
Gelb, M. 1994. Ryhtiä elämään. Johdatus Alexander-tekniikkaan. Suomentanut Päivi Saraste-Halme. Porvoo: WSOY.
Giampieri, A. s.a. 16 studi giornalieri di perfezionamente. Milano: Ricordi.
Gillet, F. s.a. Études pour l'enseignement superieur. Paris: Leduc.
Giot, M. 1985. L'ABC du jeune hautboïste 1, Paris: Billaudot.
Giot, M. 1987. L'ABC du jeune hautboïste 2, Paris: Billaudot.
Goossens, L. & Roxburgh, E. 1977. Oboe. London: Macdonalds and Jane's.
Gossett, C. W. 1989. Electromyographic investigation of the relationship of the effects of selected parameters on concurrent study of voice and oboe. Journal of voice 3 (1), 52-64.
Guz, A., Noble, M. I. M., Eisele, J. H. & Trenchard, D. 1970. The role of vagal inflation reflexes in man and other animals. In Breathing. Hering - Breuer centennary symposium. London: J & A Churchill, 17-40.
Hart, C. W., Goltman, C. L., Schupbach, J. & Santucci, M. 1987. The musician and occupational sound hazards. Medical problems of performing artists 2 (March), 22-25.
Hilton, L. B. 1951. Oboe playing and breath support. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1951, May-June), 435-436.
Hinke, G. A. s.a. Elementarschule. Leipzig: Peters.
Hovey, N. V. s.a. Rubank elementary method: oboe. Chicago: Rubank.
Jago, J.P. 1978. Medical and dental problems of musical instruments. British medical journal 4, 1295.

Johnson, K. 1986. Trumpetinsoiton taito. Suomentanut Timo Mäkinen. Hyvinkää: Suomen trumpettikilta.

Joppig, G. (1981). Oboe & Fagott: ihre Geschichte, ihre Nebeninstrumente und ihre Musik. Bern:Hallwag.

Kaplan, J. & Greiner, M. 1984. Coping with commercial oboe reeds. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1984, March), 522-524.

Kubát, A. 1961. 50 etudes in phrasing. Praha: Supraphon.

Lacour, G. s.a. 50 études faciles et progressives. Paris: Billaudot.

Lamorlette, R. s.a. Douze études pour le hautbois. Paris: Leduc.

Lamotte, A. 1974. Dix-huit études pour hautbois ou saxophone. S.l.: Braun.

Landis, B. & Carder, P. !972. The eclectic curriculum in American music education: contributions of Dalcroze, Kodaly and Orff. Reston, Va.: Music educators national conference.

Langey, O. (1965). Practical tutor for the oboe and the cor Anglais. Revised edition. London: Boosey & Hawkes.

Lederman, R. J. 1986a. Nerve entrapment syndromes in instrumental musicians. Medical problems of performing artists 1 (Jun.), 45-48.

Lederman, R. J. & Calabrese, L. 1986b. Overuse syndromes in instrumentalists. Medical problems of performing artists 1 (March), 7-11.

Ledet, D. 1981. Oboe reed styles: theory and practice. Bloomington: Indiana University Press.

Leonard, N. 1960. Harmonic fingerings for oboe. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1960, May), 452.

Lindholm, H. 1985. Flautissimo. Kuopio: Kuopion Työkeskus.

Locker, B. K., Edelfsen, B. E. & Williams, W. S. 1981. Polymer impregnation for stabilization and protection of oboe reeds. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1981, Feb.), 507-511.

Lockwood, A. H. 1988. Medical problems of secondary school-aged musicians. Medical problems of performing artists 3 (Dec.), 129-132.

Loyon, E. 1925. 32 études pour hautbois ou saxophone. Paris: Billadout.

Luft, J. H. s.a. Etüden für 2 Oboen, op. 11. Berlin: Bote & Bock.

Mandel, S., Patterson, S. & Johnsson, G. 1986. Overuse syndrome in a double bass player. Medical problems of performing artists 1 (Dec.), 133-134.

Mille, K. 1954. Zwanzig Studien für Oboe. Leipzig: Hofmeister.

Mountcastle, V. B. 1980. Medical physiology Vol. 2: The Circulation (p 949), The Respiration (p 1675). London: C.V. Mosby.

Navratil, M. & Rejsek, K. 1968. Lung function in wind instrument players and glassblowers. Annals of the New York Academy of Sciences 1968-69;155:277-83.

Nies, A. S. 1986. Clinical pharmacology of beta-adrenergic blockers. Medical problems of performing artists 1 (March), 25-26.

Nizet, P. M., Borgia, J. F. & Horvath, S. M. 1976. Wandering atrial pacemaker (prevalence in french hornists). Journal of electrocardiology 9 (1), 51-52.

Palonen, O. 1993. Aspects of musical life and music education in Finland. Second revised ed. Helsinki: Sibelius Academy. Series of educational publications 8.

Piha, S. J. 1988. Cardiovascular autonomic function tests. Turku: Publications of the Social Insurance Institution Finland.

Piha, S. J. 1989. Autonomisen hermoston toimintakokeet. Turku: Kansaneläkelaitoksen kuntoutustutkimuskeskus.

Plamenac, P. & Nikulin, A. 1960. Atypia of the bronchial epithelium in wind instrument players and in singers: a cytopathological study. Acta cytologica 13 (5), 274-278.

Porter, M. M. 1967. Dental problemsin wind instrument playing. Reprint of 12 articles publishen in British dental journal, volumes 123 and 124 (Oct. 17, 1967 to Apr. 2, 1968). London: British dental association.

Prestini, G. 1944. Raccolta di studi per oboe. Milano, Ricordi.

Rakowski, A. 1968. Pitch of filtered noise. The 6th International Congress on Acoustics, Tokyo, Japan, August 21-28 in 1968.

Rakowski, A. 1971. Pitch discrimination at the threshold of hearing. In Seventh International Congress on Acoustics, Budapest.

Rakowski, A. 1972. Direct comparison of absolute and relative pitch. Symposium on Hearing Theory, Ipo Eindhoven, Holland, June 22-23 in 1972 .

Reimer, B. 1957. The high school oboist can be taught by the regular band teacher. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1957, Dec.), 450-452.

Roos, J. 1936. The physiology of playing the flute. Arch. Neerl. Phonetique 12, 1-26.

Rösler F. 1984. Oboe-Studies I-II. Leipzig: Deutscher Verlag für Musik.

Rossing, T. D. 1983. The science of sound. Reading, Mass.: Addison-Wesley.

Rothwell, E. 1968. Oboe technique. London and Southampton: The Camelot Press.

Rothwell, E. 1974. The oboist's companion. London: Oxford University Press.

Salviani, C. 1951. Studi per oboe: tratti dal metodo. Milano: Ricordi.

Sellner, J. s.a.(1819). Méthode pour hautbois ou saxophone. Paris: Costallat & Cie.

Socewicz, W. 1977. Major and minor scales in intervals for oboe. Kraków: PWM.

Socewicz, W. 1980. Scales, arpeggios and intervals for oboe. Kraków: PWM.

Sprenkle, R. & Ledet, D. 1961. The art of oboe playing. Evanston, Illinois: Summy-Birchard Company.

Śnieckowski, S. 1985. Wybór etiud na obój 1-3. Kraków: PWM.

Śnieckowski, S. 1988. Scales for the french oboe. Kraków: PWM.

Szeszler, T. 1956. Oboaiskola 1-2. Budapest: EMB.

Tahvanainen, K. s.a.(1989). Cardiovascular autonomic function tests using a microcomputer. Unpublished.

Teirilä, M. & Salorinne, Y. 1990. Soittoon liittyvät haitalliset oireet ammattimuusikoilla. Teoksessa Kurkela, K. (toim.) Näkökulmia musiikkiin, SIC 3. Helsinki: Sibelius-Akatemia, 127-142.

Thomas, O. E. 1981. Oboe respiration. Woodwind anthology, Vol. 1 (Paper originally published in The instrumentalist 1981, Aug.), 513-515.

Tolksdorf, A. & Rösler, F. 1978. Schule für Oboe I-II. Leipzig: Deutscher Verlag für Musik.

Viljanen, A. A. 1970. Patterns of motor activity in breathing in response to varying sensory inputs. In Breathing. Hering - Breuer centennary symposium. London: J & A Churchill, 183-206.

Voxman, H. 1942. Selected studies for oboe. Chicago: Rubank.
Voxman, H. s.a. Rubank advanced method for oboe. Chicago: Rubank.
Wapnick, J. & Freeman, P. 1973. Effects of dark-bright timbral variations on the perception of flattness and sharpness. Journal of research in music education 23, 176-184.
Wastall, P. 1990. Learn as you play oboe. London: Boosey & Hawkes
Weber, J. & Chase, R. A. 1970. Stress velopharyngeal incompetence in an oboe player. Cleft Palate Journal 7, 858-861.
Weisberg, A. 1975. The art of wind playing. New York: Shirmer.
West, J. B. 1983. Respiratory physiology. Baltimore: Williams & Wilkins.
Wiedemann, L. 1950. 45 Etüden für Oboe. Leipzig: Breitkopf & Härtel.
Winberg, L. 1980. Suzuki-opetusmenetelmästä. Helsinki: Hellas.