Interaction of chest wall and abdominal muscles in wind instrument players

A preliminary report

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Four experienced brass-instrument players and one rank novice whistle player were studied to determine the relative contribution of the thorax and abdomen to expiration during repetitive playing of a simple refrain. Respiratory inductive plethysmography was used to record volume changes of the chest cage and abdomen separately and to measure end-inspiratory lung volumes preceding each chorus. There was considerable variation between performers in the timing and magnitude of thoracic and abdominal contributions to expiration. These variations were likely due to the physical requirements of the different musical instruments. End-inspiratory lung volumes were much more consistent in the skilled players than in the novice.

Index terms: Lung volume measurements • Music

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Breath control and breathing techniques are matters of great concern to all wind instrument players. Tonal quality is generally attributed to proper breathing, and purity of tone can be a major distinguishing feature between performers of equivalent technical skill. Wind instruments have been studied to determine how a change in any of their myriad shapes and dimensions alters their acoustic properties.[1–3] Others have reported on the airflows and mouth pressures necessary for sound generation in different wind instruments.[4,5] In contrast to these detailed studies of the physical properties of wind instruments and the physiological demands they impose upon their users, there have been few reports of how performers actually generate the requisite mouth pressure and airflow their instruments

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require. What specific muscle groups are employed, how they interact with other muscles, and what the respiratory muscles do during changes in tone, pitch, or amplitude are unknown.

To wind instrument players, the term *breath control* pertains almost exclusively to the expiratory phase of the breathing cycle. This is understandable since sound is created by the instrument only during expiration. However, the ability to regulate timing, volume, and other aspects of inspiration is equally important.

In addition to creating a pleasing tone, skilled performers can play a passage repeatedly with little if any detectable variation in tone, pitch, amplitude, or musical quality. If this consistency is related to breath control, it seems likely that the inspiratory maneuver that precedes each passage might be a critical factor in how well or how poorly the subsequent passage is played.

It would be helpful to both students and teachers of music if some objective measurement could be established to correlate physical performance with artistic ability.

In this preliminary study, I have attempted to measure and compare the relative contribution of the chest wall and abdominal muscles to the expiratory effort, and the consistency of end-inspiratory lung volumes of wind-instrument players.

Methods

Four skilled musicians and one rank novice served as subjects for this study. The four musicians were in their middle to late twenties in a university graduate music school program. They were free of cardiorespiratory disease. Only brass players were selected because measuring airflow is much simpler through brass instruments than through woodwinds. The fifth performer was in his early sixties and played a penny whistle, a toy suitable for playing simple tunes. All performers played the same selection, "Mary Had a Little Lamb," repeatedly, stopping only momentarily between choruses for a rapid inspiratory gasp. Except for the tuba player, who sat on a high stool, all players stood. A large plastic funnel was taped to the bell of the trumpet, trombone, and French horn, and a pneumotachograph was affixed to the cutoff small end. The pneumotachograph was mounted between the mouthpiece and the shaft of the penny whistle and replaced one of the many slides of the tuba. The pneumotachograph signal was displayed on an analog meter. Each performer observed the meter while playing and attempted to maintain the indicator at a fixed position to assure a constant expiratory flow. A respiratory inductive plethysmograph was used to determine the thoracic, abdominal, and lung volume changes during playing, and the volume of the inspiratory gasp that preceded each chorus. The inductive plethysmograph[6] consists of a wire sewn into elastic binders that encircle the mid-chest and lower abdomen, plus associated electronics. Each binder is connected to an oscillator. Signals proportional to the changes in the volume of each compartment and their sum are available. Calibration was performed by inspiring to approximately half the total lung capacity, clamping the nose, and with the mouth closed, alternately contracting and relaxing the abdominal muscles while keeping the glottis open. Since the volume of air in the subject remains constant during this maneuver, volume changes in the chest or abdomen are equal and opposite in direction.[7] Amplifier gains are adjusted accordingly. Final calibration of the summed output from both binders was made by concurrent recording from the inductive plethysmograph and from a spirometer. The thoracic, abdominal, and summed volume changes were recorded on a multichannel recorder during repetitive choruses played either forte or piano.

Results

Both the skilled performers and the novice combined their rib cage and abdominal contribution to expiration in a smooth, coordinated manner, but there were considerable differences in how this was done. Expiratory airflow was maintained at a constant value by all except the tuba player. The end-inspiratory lung volumes achieved by the penny whistle and tuba players were markedly irregular, whereas those of the other performers were much more consistent. No quantitative measurements are reported because of the limited number of subjects tested. Individual results can best be judged from the plethysmographs (*Figs. 1–6*), which contain a segment of the graphic record of each performer. From six to 14 consecutive choruses are shown. The top of the trace represents expanded volume of lungs and abdomen at the onset of the chorus. Continuous vertical time lines are 5 mm apart. Paper speed equals 1 mm/sec. The upward,

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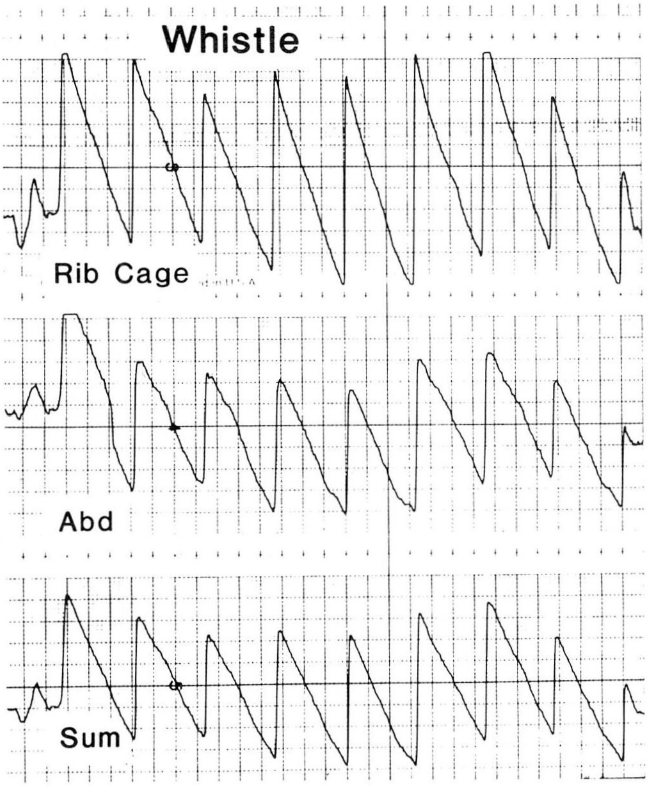

Fig. 1. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a penny whistle player.

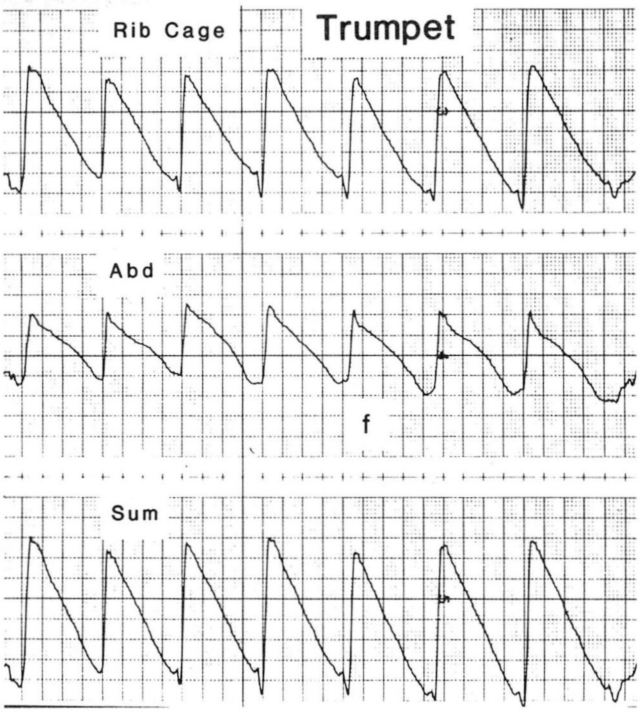

Fig. 2. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a trumpeter playing at high sound volume. *f* = forte.

nearly vertical portion of the trace is the inspiratory gasp preceding each chorus. Expiration appears as a slanting line downward from left to right, and the slope of the line represents expiratory airflow. Eight complete choruses are shown.

Each player established his own tempo and took 15 to 20 seconds to complete the refrain. The record of the penny-whistle player (*Fig. 1*) reveals a constant rate of volume change of both rib cage and abdomen from the beginning to the end of each chorus, with abdominal volume changes approximately two-thirds those of the thorax. The end-inspiratory volume is irregular and varies by as much as 30% of the inspiratory volume. A different pattern of volume change is apparent in the record of the trumpeter during a forte rendition (*Fig. 2*). The rib cage contribution to the expiratory effort is about twice the abdominal contribution and at the conclusion of each chorus there is a small, rapid additional expiration as shown on the rib cage and sum tracings. This represents a small expiratory puff at the conclusion of the chorus. There is some irregularity of the end-inspiratory lung volume, but it is considerably more stable than that of the previous performer. Records made by the same trumpeter while playing at a lower sound volume (*Fig. 3*) show the same basic pattern, but the rapid expiration at the conclusion of each chorus is large. This is most obvious in the rib cage tracing, but there is considerable assistance from the abdomen. The French hornist (*Fig. 4*) used his abdomen and thorax in similar fashion and demonstrated similar end-inspiratory volume consistency. Note that in the middle of the record (*Fig. 4,* arrow) he felt obliged to "sneak" a breath at the midpoint of one chorus. His record demonstrates a rapid volume decrement of both rib cage and abdomen at the onset of play. Although the sound produced was not recorded, this initial spike likely precedes the onset of sound and represents intrathoracic gas compression as oral pressures are increased sufficiently to initiate oscillation of the lips and sound generation. A similar, but less obvious pattern of a rapid volume decrement at the onset of play can be seen in the record of the trombonist (*Fig. 5*). He did not

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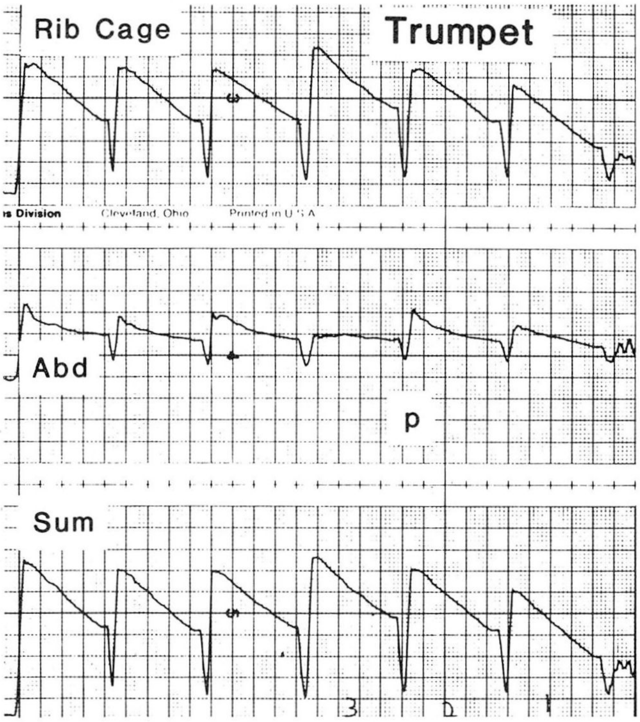

Fig. 3. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a trumpeter playing at low sound volume (*p*).

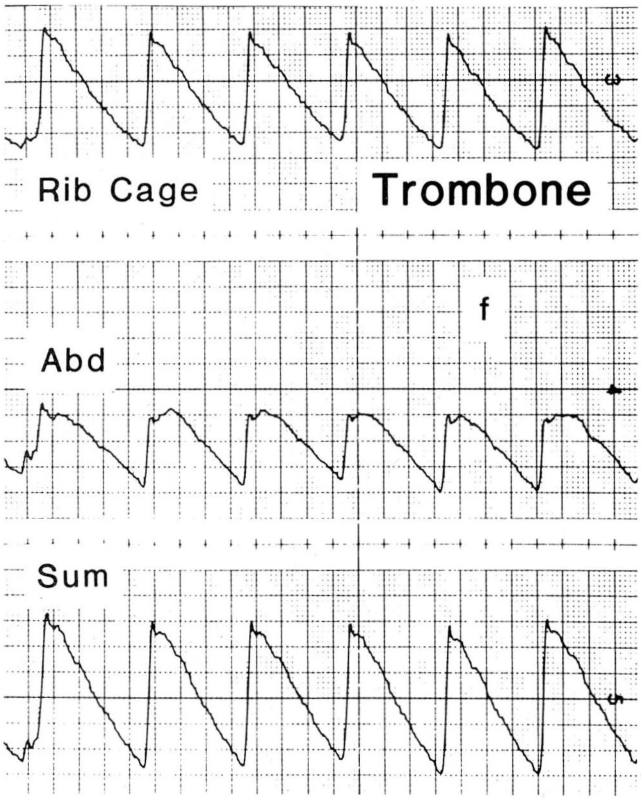

Fig. 5. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a trombonist playing at high sound volume (*f*).

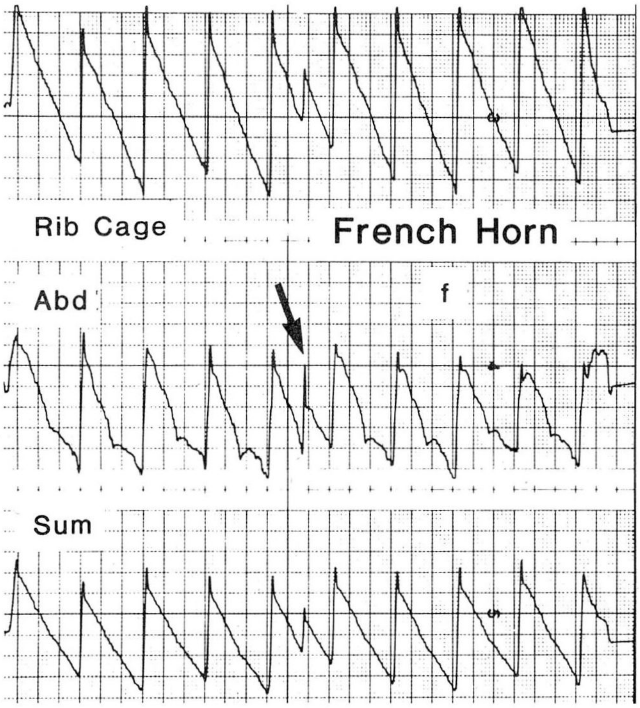

Fig. 4. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a French hornist. Arrow indicates inspiration in the middle of a chorus.

demonstrate the simultaneous contribution of rib cage and abdomen throughout expiration that is seen in the previous performers. At the onset of play only the rib cage is shown to contribute, with the abdominal contribution occurring during the final three fourths of the chorus. End-inspiratory volumes are reasonably constant. There are no substantial differences in the tracings of the trombonist when he played loudly or softly. A decrease is seen in inspiratory volume of approximately 10% when the trumpet, trombone, and French horn players changed from playing loudly to softly. This volume effect was not measured in the other performers. The tuba player's graph looks considerably different from all of the others, but it should be remembered that, unlike the other performers, he sat and cradled his instrument against his body while playing (*Fig. 6*). Furthermore, it was not possible for him to complete a chorus without inspiring so that two to three small, rapid inspiratory gasps are evident during each chorus. Because the body position during play differed from the position during calibration, the relative rib cage and ab-

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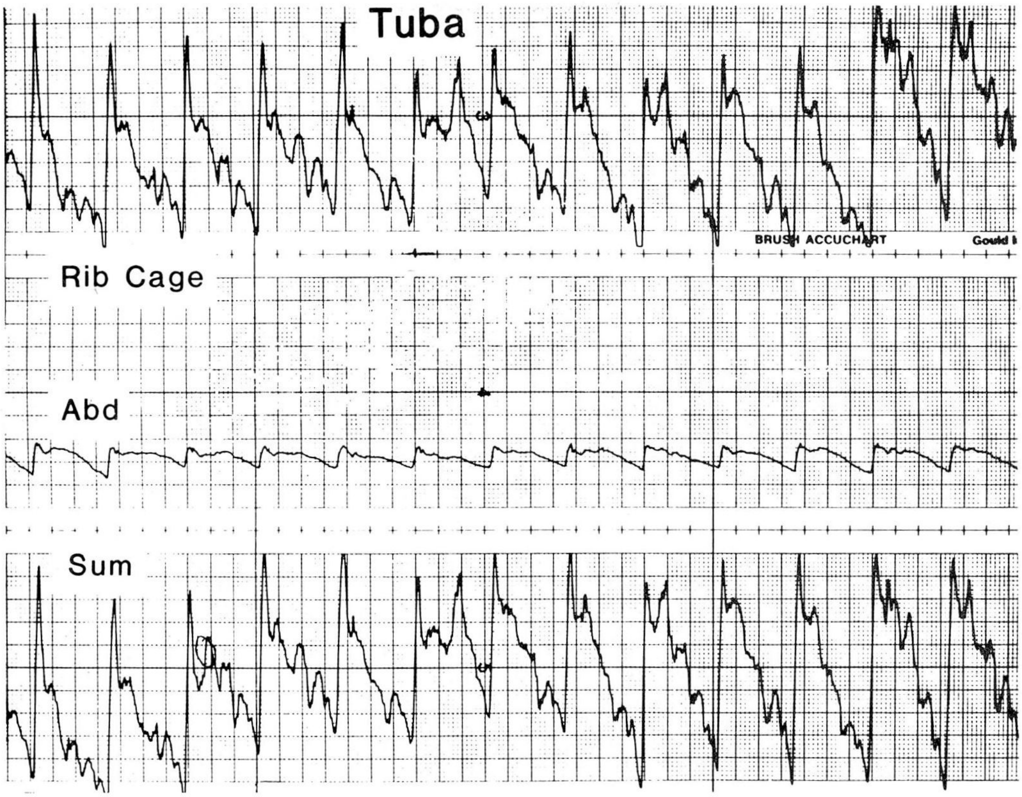

Fig. 6. Plethysmograph. Rib cage, abdomen, and sum (total) volume changes recorded of a tuba player.

dominal contributions cannot be accurately assessed. There is also a large, rapid early expiratory volume reduction similar to but even greater than that observed in the record of the French hornist.

Discussion

Wind instruments require either high rates of airflow at low mouth pressures (the larger brasses and reeds), or high oral pressures and lower airflow (the smaller instruments) (*Table*). A range of neuromuscular responses is required to meet the physical demands of the different wind instruments, a demand that is independent of the level of skill of the performer. Therefore, any study of muscle function during performance must take into account specific instrumental requirements. The different pattern of rib cage and abdominal contribution to expiration between the trumpet and trombone players (*Figs. 2* and *5*) are likely due to differences in instrumental requirements, not artistic ability. Both players had equivalent training, experience, and performance credentials, so it seems unlikely their dissimilar respiratory patterns represent different degrees of performance skill. Many performers of widely varying ability, all playing the same instrument, would need to be studied to determine which respiratory patterns are the result of the physical demands of the particular instrument and which are the result of the level of artistic skill.

Two types of inspiratory volume variation were observed. There were small, but consistent differences between the average inspiratory volume while playing loudly compared with the volume while playing softly. The other variation was the magnitude of successive, individual end-inspiratory volumes preceding each chorus. Although the significance of these loud-soft variations is not known, one can infer how they are brought about. The slight decrease in inspiratory volume when the three performers in whom it was measured played the same passage piano instead of forte represents a shift in respiratory pattern in response to performance requirements. The shift probably occurs either from the anticipation of the physical demands imposed by the music, via feedback from the chorus just completed, or a combination of both mechanisms. It is unclear if

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Table. Maximal oral pressure and airflow for musical instruments*

	Maximum pressure (mm Hg)	Maximum flow (L/sec)
Bassoon	90	0.70
Oboe	81	0.15
Clarinet	55	0.96
Flute	78	0.61
Bass tuba	78	1.68
Trombone	126	0.78
French horn	116	0.59
D trumpet	132	0.40
Bagpipe	66	2.67

*Adapted from Bouhuys[4] and Gibson.[5]

the link between inspiratory volume and sound amplitude has any relationship to performance skill. On the other hand, consistency of end-inspiratory volume—the volume of air in the thorax at the onset of play—seems more likely to have a direct connection with performance ability. This variation was similar among the three musicians in whom it could be reliably assessed, whereas the novice whistle player displayed marked variability even after several weeks of practice. These limited observations give credence to the concept that consistent end-inspiratory lung volumes while playing a repetitive passage does correlate with performance skill.

Measurement of inspiratory volumes in healthy volunteers (not musicians) has most recently been reported by Katz-Salamon.[6] Her subjects were able to detect a change in tidal volume of from 15% to 45% of a reference volume that varied from 0.5 to 1.0 L. Although no specific connection between the ability to detect a change in inspired volume and performance skill on wind instruments has been shown, there may be a connection. The subject who can detect the smallest volume change may be a better candidate than his less sensitive colleague for training as a wind instrumentalist. Even if this particular skill is not significant, some other measurement may help identify those best equipped physiologically to become outstanding wind instrumentalists.

In one of his many papers on the physiological requirements for playing various wind instruments, Bouhuys[8] attempted to correlate artistic performance with physiology. He noted that both voice and wind instrument teachers frequently "tell their students to support the tone . . . with the diaphragm rather than with the chest."[8] Even though the diaphragm is an inspiratory muscle and is essentially inactive during the playing of a wind instrument or singing, this fact has not deterred generations of teachers from urging students to use it, or countless students from attempting to do so. Respiratory inductive plethysmography was not available at the time of Bouhuys' writings, and no physical action or physiological counterpart of the support was known. Direct fluoroscopic observation of the diaphragm of a singer when a note was properly supported and when it was sung incorrectly shows no difference whatsoever in diaphragmatic movement.[9] It appears likely from the figures shown here that contraction of the abdominal muscles and concurrent reduction in abdominal volume occurs during efforts to support the tone, although no specific instructions to do so were given to these performers.

Additional measurements of performers of varying degrees of skill using these same techniques can provide quantitative data that may identify physiological correlates of artistic performance.

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