

Stethoscope Acoustics

II. Transmission and Filtration Patterns

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THERE are no reliable acoustical data to aid physicians in their selection or use of a stethoscope. Yet, the sole medical utility of any stethoscope is derived from its acoustical performance. It is the purpose of this paper to provide clinicians with objective acoustical performance data on intact and current stethoscopes.

Frederick and Dodge¹ first recognized that the stethoscope was deserving of acoustical study in 1924. They studied the intact stethoscope, but their data understandably reflected the limitations of acoustical test instruments of the time. In 1940, Johnston and Kline² made an objective acoustical study of stethoscope components. Their test method was physiologically oriented and employed a sound source implanted within a cadaver heart. They concluded that the design of the chestpiece was an important determinant in shaping the response of a stethoscope. Rappaport and Sprague^{3, 4} studied stethoscope tubing. They interpreted their data to indicate that the physical properties of tubing had considerable influence on stethoscope efficiency. Groom^{5, 6} investigated stethoscope performances through well-executed subjective studies. He called attention to the importance of well-fitting earpieces and cited the impairment of stethoscope performances caused by air leaks and ambient noise levels. However, we have been unable to find any fully calibrated objective data published on the acoustics of intact stetho-

scopes since the means have been available to perform calibrated studies.

The American Standards Association was established as the organ through which acoustical test methods became standardized. Test procedures were set up for the evaluation of many acoustical devices,⁷ (earphones, microphones, and loudspeakers) but no standard method has been adopted as yet for the testing of stethoscopes. We developed a new acoustical test method⁸ specifically designed to obtain calibrated response curves on intact stethoscopes. It provided the means of testing the instruments while they were actually being worn by physicians. It was observed that the acoustics of human ears became an integral part of the acoustics of stethoscopes. In short, human ears alter the performance of a stethoscope. Thus, in order to standardize the testing of stethoscopes, it is necessary to incorporate "standard ears" into the test system. There is no such thing as an unvarying "standard" human ear, but the acoustical contributions of such a hypothetical ear are now known. We employed a mechanical analog ear⁹ which has the same influence upon the acoustics of a stethoscope as does the calculated average normal human ear. This paper will describe the properties of the analog ear and the acoustical response patterns of a sampling of currently available stethoscopes. All data in this paper are objective.

Method*

The test method is identical in all respects to method B described in the preceding paper⁸

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*This test method is being employed in further acoustical studies. For the purpose of clarity, it will be referred to as the MHA Stethoscope Test System. It is named for the Michigan Heart Association whose support made possible its development.

(see fig. 5 part I, page 892 of this issue) except that stethoscope earpieces are terminated into artificial ears rather than into human ears. Sound input to the stethoscope chestpiece is held constant throughout the test frequency range from 20 to 3,000 cps. Stethoscope outputs are measured by the probe technique at the earpiece—"auditory canal" junction as in humans. Both the input signal and the stethoscope output are recorded on a synchronized oscillator-recorder system. All tests were carried out in a sound-proof room. The entire test system was fully calibrated in absolute units.

The Average Human Ear

Data obtained from the preceding studies of stethoscopes and humans were utilized to determine the acoustical influence of the average normal ear upon the acoustics of a reference stethoscope. Variations in the response of this instrument were determined in a series of 20 subjects with proven normal hearing. The mean response curve was arithmetically calculated from these data at frequency points pertinent to the response curve of the stethoscope. This was taken as the standard curve representing the response of the reference stethoscope coupled with the average human ear. Artificial ears were then designed to duplicate the average human curve with the reference stethoscope.*

The Artificial Ear (Mechanical Ear Analog)

The artificial ear is in the form of an impedance chamber consisting of a series of interconnected air cavities (fig. 1). The dimensions of these cavities were based upon calculations kindly supplied us by Josef Zwislocki (personal communication, 1963) of Syracuse University. The cavities are bored from solid aluminum. The distal end of the artificial ear is closed, and its proximal end contains the opening which receives the stethoscope earpiece. The proximal cavity is connected to a distal cavity through a minute passage (1 mm in diameter). The proximal cavity could be said to approximate the external auditory canal. The 1.0 mm passage acoustically represents the impedance of the middle ear structures, and the distal cavity approximates the acoustics of the inner ear. Precise anatomic correlations were not attempted nor are they pertinent. The purpose of the ear analog is to duplicate the overall terminus acoustics of the average human ear within the stated frequency range.

*The stethoscope selected as the reference instrument was the Army Ford's. It possesses a regularity in its response curve which facilitated the frequency location of data points in calculating the mean response.

Stethoscopes Studied

Twenty-eight unaltered commercial stethoscopes were tested against the artificial ears. This sampling included the more popular models currently available in this country, plus a number of imports and lesser-known instruments. We have not attempted a complete cataloging of all stethoscopes past and present.

Each instrument was fully assembled and checked for air leaks. Several were found to have air leaks in their chestpieces although they were new and unused. These were replaced with air-tight ones. The earpieces of each stethoscope were inserted into a pair of artificial ears in the same fashion as they would be worn by humans (fig. 2). The probe was positioned at the earpiece, "auditory canal" junction, either by insertion through the wall of the artificial ear (fig. 1) or through a hole drilled in the stethoscope earpiece (fig. 2). Identical responses were seen with either insertion, and the route selected was usually the former as a matter of convenience. A silastic cushion held stethoscope earpieces in place and assured air-tight seals. The chestpiece was clamped to the sound stage of the test apparatus as in method B (fig. 2). A petroleum jelly sealant prevented air leaks at the contact surface. Through the use of support rings, diaphragms were not permitted contact with the sound stage. This prevented any damping from nonvibratory contact.

Presentation of Data

The intensity level of the input signal was held constant at 80 db referenced to 0.0002 dyne/cm.² For the purpose of comparing the output of a stethoscope to its input, it is convenient to designate the constant input signal at the 0 db level. Thus, whenever stethoscope output (response)

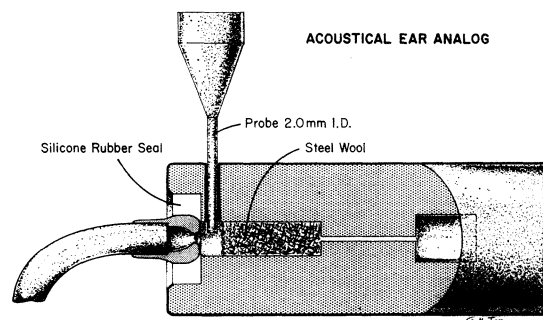


Figure 1

Stethoscope earpiece seats firmly into a silastic (silicone rubber) grommet. Its outlet lumen is flush to opening of artificial ear. Microphone probe inserts to the midpoint of this junction. Steel wool (grade 00) fills proximal cavity and functions as damping material.

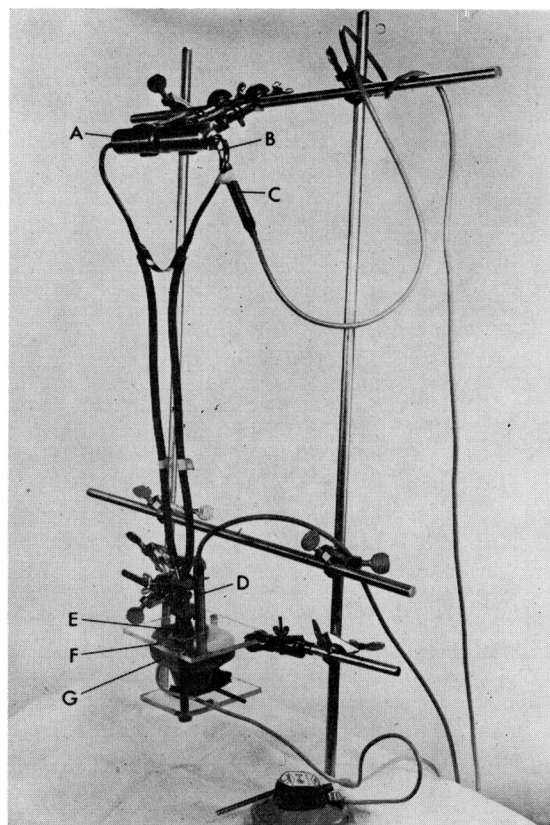


Figure 2

The test system. (A) Artificial ears; (B) probe tube; (C) output microphone; (D) input microphone; (E) stethoscope chestpiece (bell); (F) sound stage; and (G) sound source (headphone).

exceeds its input, amplification has occurred and its amplitude is indicated by "+" db. Where attenuation has occurred, it is indicated by "-" db. The actual recording of the input signal appears as a flat line at 0 db on all graphs. Its maximum deviation from a true flat response is less than ± 0.5 db. The decibal scale appears along the ordinate and the test frequencies appear along the abscissa. This practice will apply to all data presented in this paper.

Curves obtained from bell-type chestpieces represent their transmission acoustics. Diaphragm-type chestpieces present two different acoustical patterns. Their transmission acoustics are obtained with the diaphragm removed. Though this is not their condition when in actual use, their transmission patterns are presented to delineate the acoustical contribution of the diaphragm itself. When the diaphragm is in place, sound passing through it is filtered and this pattern is designated as "filtration acoustics." Both curves are

presented on the same graph. The transmission acoustics are indicated by a superimposed tracing as a dotted line, and the filtration acoustics are indicated by solid-line curves. All solid-line curves shown are photographs of the original graphic recordings taken directly from the recorder. A complete listing of all stethoscopes tested appears in the appendix to this paper. Stethoscopes are assigned numbers in the listing which correspond to their response curves, if included in the results section of the text.

Results

Human Response Variations

A composite of 40 response curves obtained with human subjects wearing the reference stethoscope is shown in part I (see fig. 11 page 895 of this issue). The mean response was then mathematically calculated at the frequency points where peaks and troughs occurred in the overall response pattern. These points established the average response of normal ears at these selected frequencies and are indicated by white dots superimposed on the composite graph.

Response of the Artificial Ears

Figure 3 shows the response of the reference stethoscope when worn by the artificial ears. Superimposed on this curve are the cal-

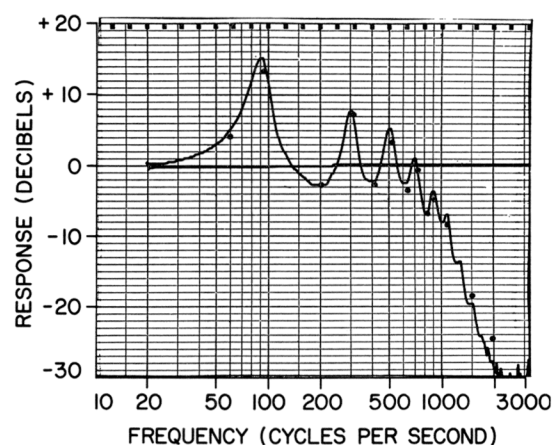


Figure 3

Response of artificial ear. Straight line at 0 db indicates input signal (direct measure). Solid-line curve is the measured response of reference stethoscope obtained with artificial ear. Closed circles show mean response with human ears (same data points as in white dots in fig. 11, part I, page 895 of this issue).

culated data points indicating the calculated response pattern of the same stethoscope coupled to average normal ears. The maximum deviations in the response of the artificial ears from the response of average human ears are +1.5 db to -3 db. This pattern was reproducible within 0.5 db on five repeat testings with the artificial ears.

Objective Stethoscope Comparisons: 1. The Transmission Patterns of Bell Chestpieces

As stated in "Methods," the response patterns of diaphragm chestpieces are considered separately from bell-type chestpieces. The following group of curves illustrate the transmission patterns of stethoscopes terminated by a bell, either singly or as a component of a combination chestpiece. There are four basic variations in the design of these instruments. These basic design features are diagrammed in figure 4. Bells were either deep and trumpet-shaped or shallow and bowl-shaped. The tubing and bell outlets were either single or double. The response patterns of all instruments within a given design group are characteristic of that group, though no two of them are identical. There are many subtle design variations which produce less significant response variations (tubing length and material, bell height and diameter, and

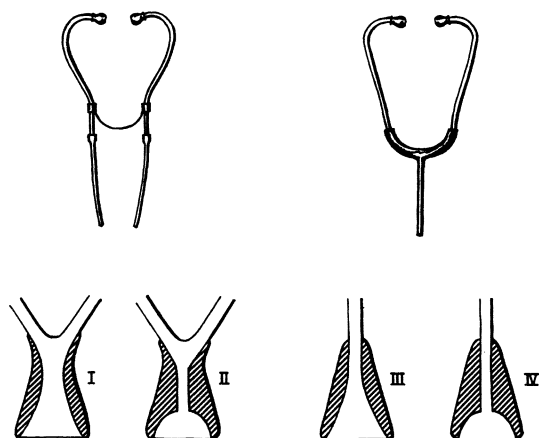


Figure 4

Basic design features of stethoscopes. (I) Double tubing, trumpet bell; (II) double tubing, shallow bell; (III) single tubing, trumpet bell; and (IV) single tubing, shallow bell.

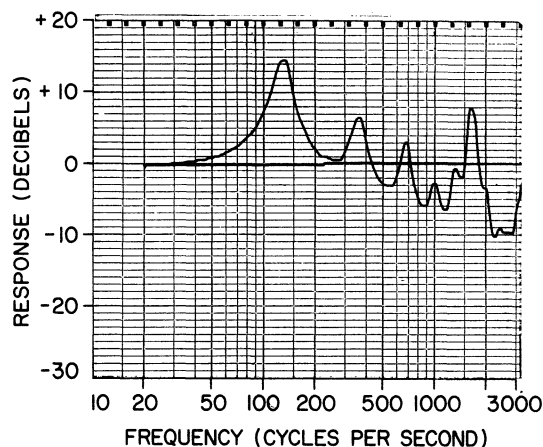


Figure 5

Response of stethoscope no. 1 (bell chestpiece); group I: double tubing, trumpet bell.

others). Two stethoscopes have been selected to represent each group.

Group I: Double Tubing, Trumpet Bell

Stethoscope No. 1 (Fig. 5). The combination of this particular trumpet-shaped bell with double tubing design resulted in the greatest range of amplification at the high frequencies of all stethoscopes tested. There are narrow troughs of attenuation at 500, 1,000, and 2,500 cps, but its peaks of amplification extend beyond 3,000 cps. No other stethoscope was found to amplify beyond 3,000 cps.

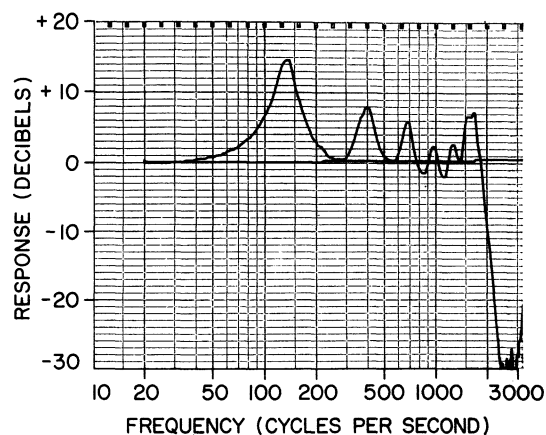


Figure 6

Response of stethoscope no. 2 (bell chestpiece); group I: double tubing, trumpet bell.

Stethoscope No. 2 (Fig. 6). It incorporates the same basic design features as stethoscope no. 1, but subtle design variations modify the response of this instrument. Its amplification peaks are more regular in contour up to 1,700 cps. But, at this point, there is an abrupt cut-off of its high frequency response. Its response pattern is smoother but of restricted range.

Group II: Double Tubing, Shallow Bell

Stethoscope No. 3 (Fig. 7). The response of this instrument typifies the effect of a shallow bell. There is progressive attenuation from 500 cps upward. Practically speaking, there is no useful high frequency response. The low frequency response, however, is good.

Stethoscope No. 4 (Fig. 8). The response of this similar model differs chiefly in that there is less amplification at the low frequencies.

Group III: Single Tubing, Trumpet Bell

Stethoscope No. 5 (Fig. 9). The low frequency (primary) peak of this stethoscope shows considerable amplification, but this is immediately followed by a trough of attenuation and a single notched peak of amplification in the mid-frequency range. There is progressive attenuation beyond 500 cps. The curve of this instrument illustrates a response characteristic common to all single-tube stethoscopes:

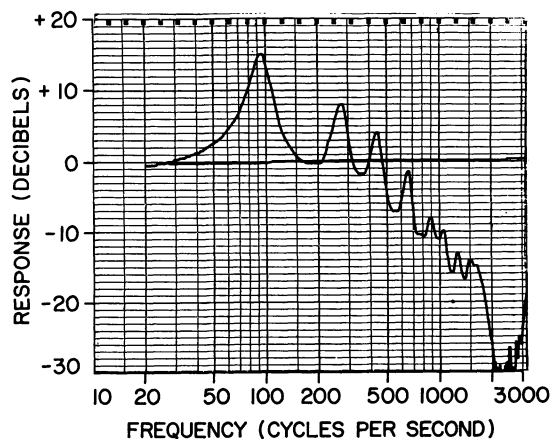


Figure 7

Response of stethoscope no. 3 (bell chestpiece); group II: double tubing, shallow bell.

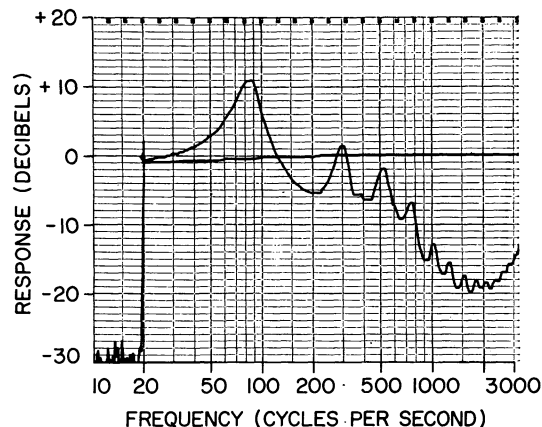


Figure 8

Response of stethoscope no. 4 (bell chestpiece); group II: double tubing, shallow bell.

there is an irregularity of the response pattern due to the superimposition of two different curve forms.

Stethoscope No. 6 (Fig. 10). There is no appreciable difference between the response of this instrument and the response of stethoscope no. 5.

Group IV: Single Tubing, Shallow Bell

Stethoscope No. 7 (Fig. 11). The primary response peak is reduced, indicating less low frequency amplification, and this is followed by insignificant secondary amplification peaks at the mid-frequencies. The general response

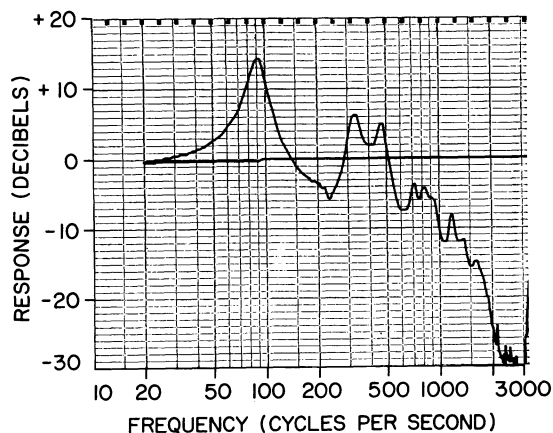


Figure 9

Response of stethoscope no. 5 (bell chestpiece); group III: single tubing, trumpet bell.

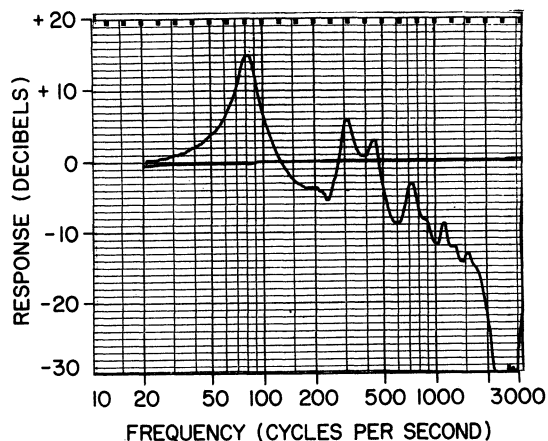


Figure 10

Response of stethoscope no. 6 (bell chestpiece); group III: single tubing, trumpet bell.

pattern is even more irregular than that of group III.

Stethoscope No. 8 (Fig. 12). The primary amplification peak is further diminished and is immediately followed by a deep trough of attenuation. There are no secondary peaks of amplification.

2. Filtration Patterns of Diaphragm Chestpieces

Sound filtration by a diaphragm is best appreciated by contrasting its response pattern with that of the same chestpiece having its diaphragm removed. In the latter condition, the chestpiece functions as a bell and

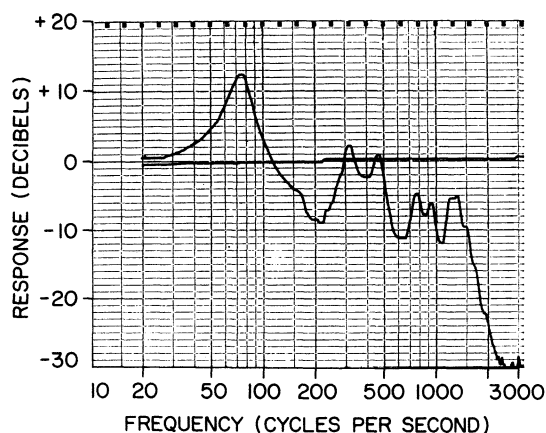


Figure 11

Response of stethoscope no. 7 (bell chestpiece); group IV: single tubing, shallow bell.

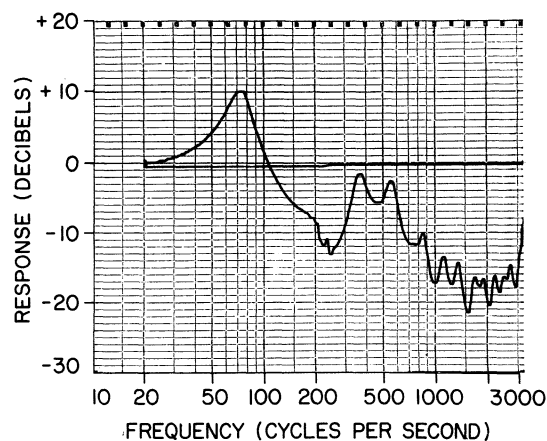


Figure 12

Response of stethoscope no. 8 (bell chestpiece); group IV: single tubing, shallow bell.

its response pattern represents the transmission acoustics of the instrument. In every case, it was found that diaphragms attenuate the transmission pattern, though there is wide variation with respect to the selectivity of this effect.

The diaphragm response of stethoscope no. 9 (fig. 13) is highly selective. It significantly attenuates low frequency sounds while permitting sound of higher frequencies to pass

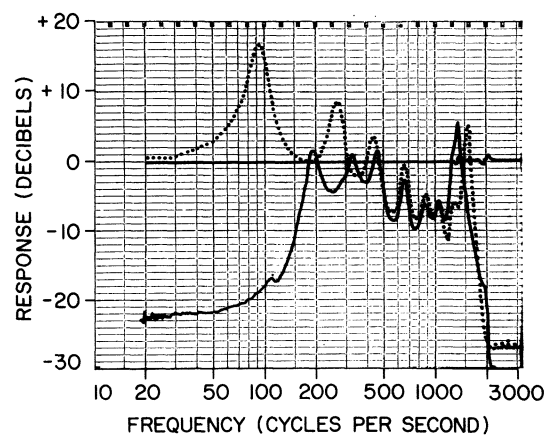


Figure 13

Response of stethoscope no. 9 (diaphragm chestpiece). Dotted line is transmission pattern (diaphragm plate removed). Solid line is filtration pattern (diaphragm on). The diaphragm attenuates low frequencies well with no significant attenuation of the transmission pattern at higher frequencies.

through relatively unchanged compared to its transmission pattern with the diaphragm removed.

Contrasted to this pattern is the filtration pattern of stethoscope no. 10 (fig. 14). This diaphragm attenuates sounds at all frequencies.

The diaphragm of stethoscope no. 11 (fig. 15) selectively filters out low frequency sound and it permits the passage of high frequency sound with relatively little attenuation. However, the basic design of the instrument has resulted in a transmission pattern characterized by progressive attenuation above 150 cps. The diaphragm does not overcome transmission deficiencies.

3. The Modern Stethoscope Compared to Laennec's

Figure 16 permits a side-by-side acoustical comparison of a modern, trend-setting stethoscope with a replica of the Laennec wooden stethoscope of 1819. This is a straight rigid tube 33.5 cm long with a bore diameter of 8 mm. It terminates in a shallow bell 4.0 cm in diameter. The transmission pattern of stethoscope no. 12 is the original solid-line recording. The response curve of the Laennec stethoscope is superimposed on the chart paper as the interrupted line. The Laennec stethoscope

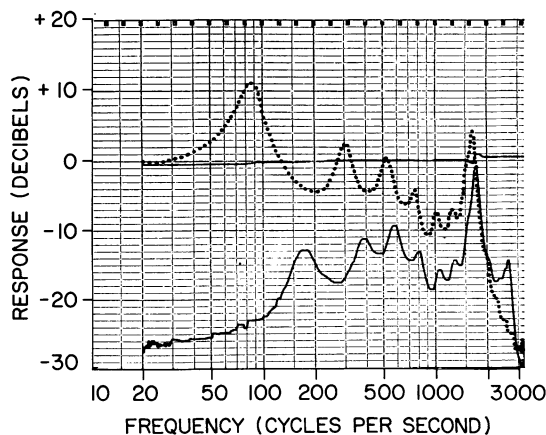


Figure 14

Response of stethoscope no. 10 (diaphragm chestpiece). Dotted line is transmission pattern (diaphragm plate removed). Solid line is filtration pattern (diaphragm on). The diaphragm attenuates at all frequencies.

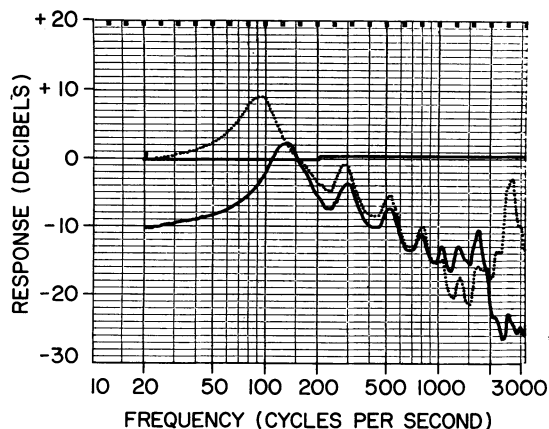


Figure 15

Response of stethoscope no. 11 (diaphragm chestpiece). Dotted line is transmission pattern (diaphragm plate removed). Solid line is filtration pattern (diaphragm on). The diaphragm attenuates low frequencies while affecting high frequencies little. However, the transmission pattern itself attenuates the high frequencies and the diaphragm does not compensate.

shows considerable amplification at the middle and high frequencies, whereas stethoscope no. 12 shows only attenuation above its low primary peak.

Discussion

The stethoscope is, acoustically, an unique device in that it incorporates the acoustical

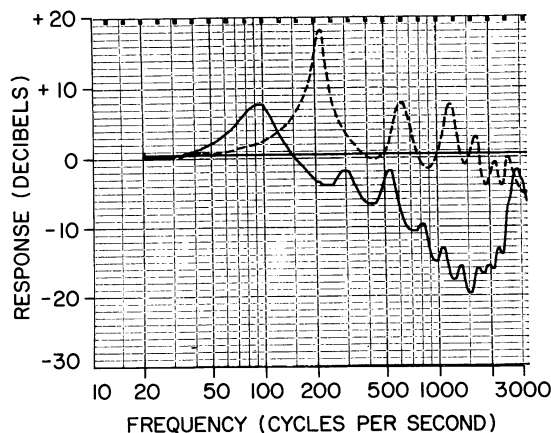


Figure 16

Response of modern stethoscope no. 12 compared to response of Laennec stethoscope. Interrupted line is transmission pattern, Laennec stethoscope (bell). Solid line is transmission pattern, stethoscope no. 12 (bell).

properties of human ears. The test method by which stethoscopes are evaluated, therefore, must do likewise. The artificial ears in our test method were designed to approximate the acoustical influence of average normal human ears upon stethoscope acoustics. The data indicate that this approximation is so close that discrepancies are too small to be audibly apparent outside a sound-proof room.* Hence, the response patterns of the stethoscopes depicted by this method can be interpreted as indicative of how the average physician hears pure tones through these instruments. When these response patterns are applied in a clinical context, it should be recalled that cardiovascular sounds are comprised of mixed frequencies, not pure tones. It has been well-documented^{10, 11} that low frequency components of a mixed sound "mask-out" the higher frequency components, and as far as the listener is concerned, the high frequency components may be faint or absent. This concept is especially pertinent to the interpretation of diaphragm filtration acoustics. When the diaphragm selectively filters out low frequencies, their masking effect is also removed. The result is that the high frequency sounds appear to the listener to be amplified. On the other hand, a diaphragm which is not selective and attenuates at all frequencies behaves more like an inefficient bell. Even if the diaphragm does filter only at the low frequencies, it is the transmission pattern of the stethoscope which determines whether there is sufficient output for the high frequencies to be audible in the first place.

In comparing the transmission patterns of intact bell-type stethoscopes, we are struck by the clustering of their responses into four distinct groups which correspond to their basic design. Group I is characterized by outputs which amplify at the higher frequencies. Group II negates this positive value of double tubing

design by utilizing a shallow bell. The result is a loss of high-frequency response despite double tubing. Single tubing design results both in an irregular distortion pattern and in a considerable loss of output at the high frequencies. Both effects were seen in groups III and IV. This is unfortunate, in our opinion, because the single tubing design is more compact, subject to less extraneous noise and looks neater. The single-tube design appears to be the trend in current stethoscope production, yet it invariably results in excessive losses at the higher frequencies. Though low frequency sounds are conceded to be important to clinical auscultation, high frequency sounds are also important and well worth preserving. High frequency sounds possess localizing properties. They do not spread as widely or with the intensity that low frequency sounds spread across the chest wall.¹⁴ Certainly, the ability to localize cardiovascular sounds to their point of origin is important to auscultation and it is the high frequencies which facilitate this. High frequencies contain the harmonics or overtones of musical sound patterns which give distinctive character to musical instruments. Similarly, the high frequency components contribute to the recognition of the distinctive characteristics of such lesions as mitral insufficiency in contrast to the murmur of a ventricular septal defect.¹⁵ Some murmurs which are of very low intensity (at or near the hearing threshold) are composed of high frequency components almost exclusively¹⁶ (for example, the murmur of aortic insufficiency). Any stethoscope which attenuates high frequencies may render such a murmur inaudible. It is also worth pointing out that senior clinicians may have lost their hearing acuity at the higher frequencies due to presbycusis and truly need amplification in this range.

In comparing the responses of modern stethoscopes to that of the Laennec instrument, especially at the higher frequencies, it is difficult to espouse an optimistic view of continuing acoustical improvement. But such a comparison must take additional factors into

*At low sound levels the ear can discriminate differences on the order of 1 db in ideal conditions and in a sound-proof room.¹² Ambient noises in clinical situations would be expected to raise the discrimination level to 3 db or more.¹³

account. The Laennec stethoscope is monaural; and hearing is more sensitive when binaural.¹⁷ The Laennec stethoscope is also a bulky, rigid device. There is no question that modern stethoscopes are far more convenient to use and aesthetic in appearance. However, the question is raised: What acoustical price are we willing to pay for convenience or appearance? In the absence of objective acoustical data on stethoscope performance, it is not difficult to see why so many models have proliferated over the years. This, in turn, reflects the overriding importance of stethoscopy to the practice of clinical medicine.

What is often overlooked is the critical nature of the performance of any stethoscope. Clinically significant sounds which are near the hearing threshold¹³ may be totally lost to the examiner if the stethoscope attenuates them by as little as 3 db. It is important to become accustomed to the acoustical peculiarities of one's own stethoscope.¹⁸ It is also important that the physician choose the right one, since he may miss sounds with one instrument which he could hear with another. A soft high-pitched murmur of aortic insufficiency may be completely inaudible to the physician whose stethoscope attenuates high frequencies, no matter how long he has owned it. The common need is for a stethoscope whose response pattern will not attenuate sounds at any clinically significant frequency, or one which will amplify at selected frequencies.

The first step toward the establishment of optimal criteria for stethoscopic performance is the adoption of a standardized test method for the total acoustical evaluation of stethoscopes. Many features of the described method would be applicable to this purpose. There is an additional requirement, however, which is the evaluation of the transducer properties of stethoscope chestpieces. It is the chestpiece of a stethoscope which converts vibrations within the viscoelastic tissues of the chestwall into sound vibrations in air. It is this acoustical function of a chestpiece which the skillful examiner manipulates when he deliberately alters the force with which he presses the

chestpiece against the chestwall. By experience he has learned that when he increases the force applied to a chestpiece, the intensity of low frequency sounds is reduced, and he is permitted unobscured appreciation of higher frequency sounds. Because the transducer acoustics of chestpieces are critically altered by the force of application, some agreement must be reached as to an optimal applied force before a study of transducer properties can have much meaning. Whatever the transducer properties of various stethoscope chestpieces may be, sound traversing a chestpiece will still be subject to the filtration and transmission acoustics described in this paper. Thus, transmission patterns and filtration patterns are pertinent in comparing the performances of stethoscopes one to another.

This test method can be utilized to investigate the acoustical influences of the component parts of the stethoscope in addition to its present application of evaluating the performances of intact instruments. Chestpieces deserve careful scrutiny since the present data indicate close correlation between chestpiece designs and performance of the stethoscope. Tubing length, diameters, and materials can also be studied in context with the total stethoscope performance and in combination with the acoustical properties of the average human ear. Of special interest is the characteristic distortion pattern introduced by single-tubing design. It is a reasonable assumption that this results from an impedance mismatch between the single tube and the two binaurals. Such assumptions can now be subject to direct experimental observations. Such studies employing the described objective test method are currently underway in our laboratory.

The calibrated subjective studies described in Part I of this presentation demonstrated that the objective response patterns of stethoscopes tested by our method agree quantitatively with what trained listeners can hear through these instruments. We conclude, therefore, that the stethoscope response patterns cited in this paper can serve as useful guides to the physician in his selection of a stethoscope, or may aid him in understanding

the acoustical properties of the one he owns. Much work remains before the stethoscope can be said to be perfected or our understanding of its usefulness can be said to be complete.

Summary

This paper describes a fully calibrated and standardized acoustical test method for evaluating the transmission patterns and the filtration patterns of intact stethoscopes. An essential component of the test system is the artificial ear which duplicates the acoustical contribution of the average human ear to the stethoscope's acoustics. The transmission patterns of bell-type stethoscopes fall into four distinct groups which correspond to their basic design features. Shallow bells and single tubing design both result in attenuation at higher frequencies. A deep, trumpet-shaped bell with double tubing design may provide amplification at higher frequencies. Diaphragms attenuate the transmission acoustics of stethoscopes. When the low frequencies are selectively attenuated, high frequencies are heard more distinctly. Some diaphragms were found to attenuate at all frequencies.

The acoustical performance of any stethoscope is critical. Any attenuation of clinically significant sounds of low intensity may render them totally inaudible. The majority of stethoscopes tested (bell and diaphragm chestpieces) attenuate high frequency sounds. The adoption of stethoscopic performance criteria is urged. Few modern stethoscopes show any significant acoustical improvement since the time of Laennec.

References

1. FREDERICK, H. A., AND DODGE, H. F.: "The stethophone," an electrical stethoscope. *Bell Sys Tech J* 3: 531, 1924.
2. JOHNSTON, F. D., AND KLINE, E. M.: An acoustical study of the stethoscope. *Arch Intern Med* 65: 328, 1940.
3. RAPPAPORT, M. B., AND SPRAGUE, H. B.: Physiologic and physical laws that govern auscultation, and their application. *Amer Heart J* 21: 257, 1941.
4. RAPPAPORT, M. B., AND SPRAGUE, H. B.: The effects of tubing bore on stethoscope efficiency. *Amer Heart J* 42: 605, 1951.
5. GROOM, D.: What constitutes an efficient stethoscope? In *The Theory and Practice of Auscultation*, edited by B. L. Segal. Philadelphia, F. A. Davis Co., 1964, p. 291.
6. GROOM, D.: Effect of background noise on cardiac auscultation. *Amer Heart J* 52: 781, 1956.
7. American Standards in Acoustics. New York, American Standards Association, 1944-1957, Z24. 3-Z24.22.
8. ERTEL, P. Y., LAWRENCE, M., BROWN, R. K., AND STERN, A. M.: Stethoscope acoustics: I. The doctor and his stethoscope. *Circulation* 34: 889, 1966.
9. ERTEL, P. Y., AND LAWRENCE, M.: An acoustical analog of the human ear. In preparation.
10. ELLIOT, L. L.: Backward masking. *J Acoust Soc Amer* 34: 1108, 1962.
11. FLETCHER, H.: *Speech and Hearing in Communication*. Toronto, D. Van Nostrand Co., 1953, p. 157.
12. FLETCHER, H.: *Speech and Hearing in Communication*. Toronto, D. Van Nostrand Co., 1953, p. 145.
13. GROOM, D.: Auscultation of faint heart murmurs. *Postgrad Med* 22: 360, 1957.
14. FABER, J. J., AND BURTON, A. C.: The spread of heart sounds over the chest wall. *Circulation Research* 11: 96, 1962.
15. BUTTERWORTH, J. S., CHASSIN, M. R., McGRATH, R., AND REPERT, E. H.: *Cardiac Auscultation*, ed. 2. New York, Grune & Stratton, Inc., 1960, p. 50.
16. GROOM, D.: The recording of heart sounds and vibrations. *Exp Med Surg* 14: 239, 1956.
17. LANGFELD, H. S.: *Handbook of Experimental Psychology*. New York, John Wiley & Sons, Inc., 1951, p. 996.
18. NADAS, A. S.: *Pediatric Cardiology*, ed. 2. Philadelphia, W. B. Saunders Co., 1963, p. 9.

See page 909 for Appendix.

Appendix

*Stethoscopes Tested**

Instrument identification	Manufacturer or supplier
A. Published response curves	
Reference stethoscope = Army-Ford's (bell)	Geo. P. Pilling & Son
No. 1 Sklar (bell type)	Sklar Company
No. 2 DeLee-Hillis, Fetuscope (bell)	Dittmar & Penn Corp.
No. 3 Rieger-Bowles, Med. (double stem bell)	Geo. P. Pilling & Son
No. 4 St. George's Hospital, Leatham (small bell)	Chas. F. Thackray Ltd.
No. 5 Gordon (single stem bell)	Geo. P. Pilling & Son
No. 6 Rieger-Bowles (single stem bell)	Geo. P. Pilling & Son
No. 7 Fleischer Dual (bell)	Becton, Dickinson & Co.
No. 8 Allen Type V (bell)	Allen Medical Instr. Co.
No. 9 Rieger-Bowles, Med. (double stem diaphragm)	Geo. P. Pilling & Son
No. 10 St. George's Hospital, Leatham (diaphragm)	Chas. F. Thackray Ltd.
No. 11 Littmann Combination (diaphragm)	Cardiosonics
No. 12 Littmann Combination (bell)	Cardiosonics
B. Unpublished response curves	
Adams Non-chill (single stem)	Clay-Adams Inc.
Army-Ford's (aluminum bell)	Dittmar & Penn Corp.
B-D (single stem bell for "Triple Change")	Becton, Dickinson & Co.
Bowles (diaphragm)	Propper
Cardiophone, Reichardt	Bittner Corp.
Combination Stethoscope	Propper
DeLee-Hillis (with Ford bell)	Carstens
DeLee-Hillis (non-chill bell)	Dittmar & Penn Corp.
Fleming Micro-phonic	Grafco
Ford-Bowles (double stem)	Geo. P. Pilling & Son
Gordon (double stem)	Geo. P. Pilling & Son
Littmann Pediatric	Cardiosonics
Penn-Midget	Dittmar & Penn Corp.
Rappaport-Sprague	Sanborn Co.
Sprague-Bowles, Med.	Geo. P. Pilling & Son
Swivel-Bowles	Geo. P. Pilling & Son
Tycos Howell	Taylor Instrument Co.

*Both the bell and the diaphragm components were tested on all combination-type instruments. All diaphragm-type chestpieces were tested with the diaphragm plate in place and with it removed.

