AN IMPROVED RESPIRATION MAGNETOMETER FOR LABORATORY AND DIVING STUDIES

by

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SUMMARY PAGE

THE PROBLEM

To determine the conditions under which the respiration magnetometer will measure lung volume accurately and to evaluate possible applications in diving and respiratory research.

FINDINGS

A high degree of accuracy in measuring tidal volume and minute ventilation was achieved for immobile, supine subjects. The accuracy was not affected by light breathing resistance or by increased levels of ventilation. Changes in spinal curvature were found to be the most common source of error. Calibration based on a comparison of magnetometer and wet spirometer records during rebreathing was effective but time consuming. Data reductions could be improved by automation.

APPLICATIONS

The respiration magnetometer's insensitivity to environmental changes and its freedom from mouthpieces, masks, neck seals or other encumbrances, make it useful for prolonged monitoring of respiration for hyperbaric studies in the supine position.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4306.02-7060BAK9, Regulation of Respiration and Circulation in Humans in a High Pressure Environment. The present report is No. 1 on this Work Unit. It was approved for publication on 16 July 1970, and designated as SubMedResLab Report No. 634.

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ABSTRACT

A model of a respiration magnetometer, similar to one described by Mead*, was constructed at the Naval Submarine Medical Research Laboratory, Groton, Connecticut, by Parrot and Miller and later modified for greater reliability and ease of operation. Good correlation between output signal and lung volume was found, with supine subjects giving the most consistent results. The advantage of operation without need for mouthpiece, mask or neck seal, and the instrument's insensitivity to environmental changes, make it promising for prolonged studies of gas exchange and for hyperbaric research within its present limitations. A system for streamlined calibration and data reduction is proposed.

** From Harvard School of Public Health - see Reference 1.*

AN IMPROVED RESPIRATION MAGNETOMETER FOR LABORATORY AND DIVING STUDIES

INTRODUCTION

The use of a magnetometer to measure lung volume was first demonstrated in 1967 by Mead.[1,2] When a magnetic field is generated by an oscillator and coil, the strength of the field measured by a receiving coil depends on the separation. The respiration magnetometer is used to determine the anteroposterior diameter of the chest at the nipple and navel levels. These two signals, when added in the proper proportion, produce an analog signal which is related to a unique lung volume.

The potential of this technique for studies of underwater swimmers, for long-term investigations into the relationship between respiration, circulation and gas exchange, and hyperbaric chamber experiments was considered and a program undertaken to build and test a device at the Submarine Medical Research Laboratory in Groton, Connecticut.

The objectives of the project covered in this report were to make improvements on the circuit as designed by Parrot and constructed by Miller[3] and to refine techniques for utilizing the magnetometer in respiration studies.

DESCRIPTION OF MODIFICATIONS TO MAGNETOMETER AND EXPERIMENTAL METHODS

Numerous problems existed with the magnetometer when the project got underway. Originally the circuit had no means of balancing abdomen and thorax signals. It was necessary to add the signals externally in a voltage dividing circuit. The divider was used to balance the signals from thorax and abdomen after amplification in a Beckman Dynograph Recorder. Balancing was only possible for a limited range of body types and the chart record did not show signals in their proper proportions. Tuning was cumbersome and involved the adjustment of as many as four potentiometers. There was excessive noise in both received signals. There was no simple means of affixing the coils to a subject. No method of calibration had been devised that would allow determination of relative lung volumes, as accomplished by a common spirometer. The instrument had only been used to compare change in output voltage with change in lung volume for varying breath sizes. For consistent results this required the subject to begin each breath at functional residual capacity (FRC), since the ratio of signal change to volume change depends on the inflation of the lungs.

Several circuit changes were made to improve performance. The low frequency limit of each oscillator was very close to the resonant frequency of its receiver. The properly tuned condition was thus unstable. Reducing the capacitance in the inductance capitance (LC) loops of the receiver raised the resonant frequencies so that effective tuning was possible. A small degree of cross-talk being transmitted through poor grounds was eliminated and the feedback loop of the abdomen receiver was modified to allow gain control for internal balancing. Phase loops were added to the receiver operational amplifiers with a noticeable effect on noise and stability. Temperature characteristics were improved by substitution of higher quality components. Operating controls were all mounted on the surface of the box. They include tuning for both channels (the oscillator frequency is set for peak output using the audio output of a voltage controlled oscillator (VCO)) or a chart recorder), power ON/OFF and abdomen gain control for balancing. A HIGH/LOW range switch (S_1) extends the balancing capability over a broader range. A sum switch (S_2) changes the separate abdomen and thorax outputs to their balanced sum. Figure 1 shows the circuit as used in the following experiments.

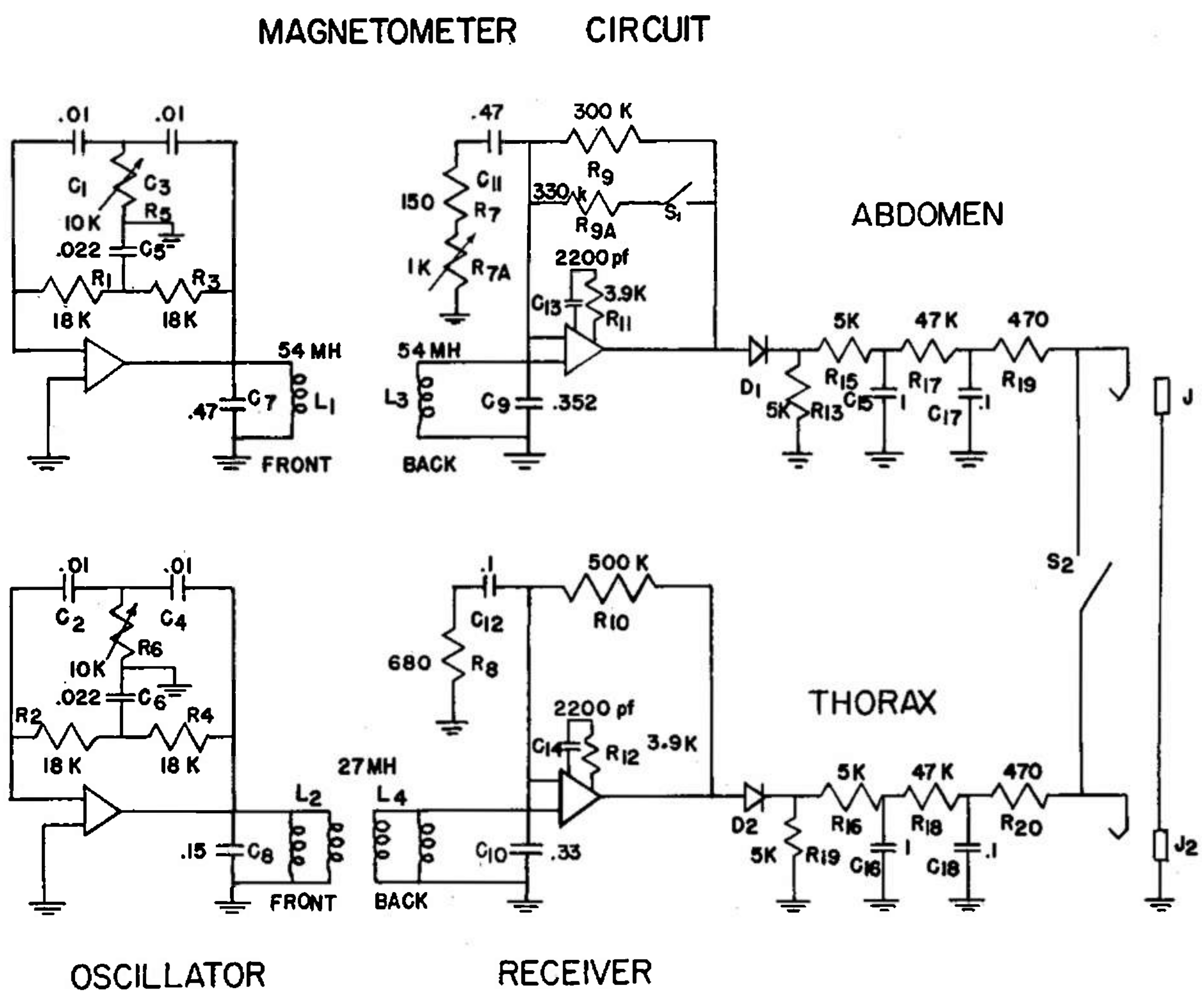

Fig. 1. Magnetometer Circuit. The circuit as it was used in the following experiment, Figures 4 through 9. Timed frequencies are about 1100 H_2 for abdomen, 1750 H_2 for thorax channels.

In addition to improving the magnetometer's electrical characteristics, several steps were taken to perfect its use. An elastic harness was made to permit wearing of the coils over street clothes. For the more critical experiments where the coils might change position, adhesive tape may be used in addition to the harness or in place of it. In place, the harness is barely noticeable and gives satisfactory results.

The most foolproof means of calibration, and that used for these experiments, consisted of a comparison of magnetometer signal with the record of a standard spirometer over a number of breaths of varying depths. From this a scale was drawn which assigned a relative lung volume to each level of magnetometer signal. The best scale was then derived by a lengthy process of curve fitting.

The relationship between signal and coil is a cubic function and that between lung volume and separation is a function with linear, quadratic and cubic terms. Because the relationship between lung volume and each signal, thorax and abdomen is a different nonlinear function, it is unlikely that proper balancing of the individual signals at one level of lung inflation will give correct balancing at all other levels of inflation.

Balancing of the thorax and abdomen signals was accomplishished in the following manner. While holding his breath, the subject moved his abdomen in and out. The abdomen gain control was manipulated to give a constant sum output during this isovolume maneuver. The process could be repeated at several levels of lung inflation to indicate the dissimilarity between the nonlinear relationships of each signal to volume. Abdomen gain was generally set for optimum balancing slightly above the subject's normal and expiratory volume.

The configuration of the equipment is depicted in Figure 2. A series of runs were conducted on three subjects, their ventilation monitored simultaneously by the respiration magnetometer and a Collins nine-liter spirometer. An Otis-McKerrow respiration valve assured one-way flow and a Med-Science recycler emptied the filled spirometer when triggered by a limit switch. CO_2 concentration was monitored at the mouthpiece using a Beckman LB-1 analyzer and recorded with the magnetometer signal on a Beckman type R dynograph.

Prior to the start of each run the subject breathed several breaths of varying volumes for calibration. During analysis a non-linear scale was drawn to optimize agreement between magnetometer and spirometer expiration tidal volume determinations. The scale was then used to read the tidal volumes of the run.

Mean values of minute ventilation, respiration rate and expiration tidal volumes for each filling cycle of the spirometer may easily be compared under a variety of conditions. Runs were conducted using three subjects sitting and supine, breathing normal air and a mixture with 4.55% CO_2, with added inspiratory resistance. Two levels of bicycle exercises were also tried for two subjects.

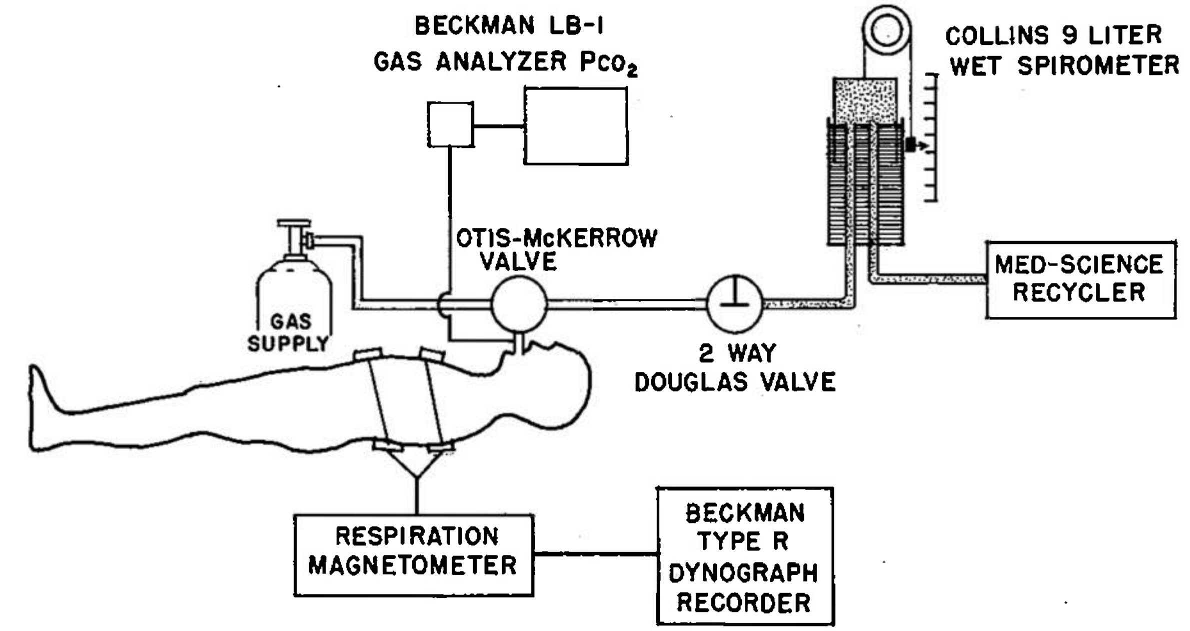

Fig. 2. *Configuration of Apparatus.*

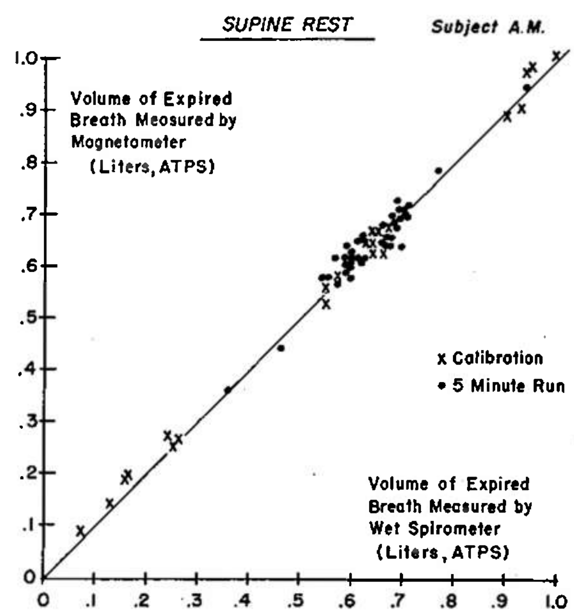

Fig. 3. *An Example of Breath by Breath Expired Volume Comparison. This data is displayed in an alternate form in Figure 5. This type of analysis is especially useful when seeking sources of error. The X's show the ability of derived scale to fit the breaths taken during calibration. The 45° line represents exact agreement between magnetometer and wet spirometer.*

RESULTS

It was generally found that with satisfactory balancing and calibration scale derivation agreement of magnetometer and spirometer volumes was excellent. Loss of accuracy was caused by changes in posture after calibration.

Effective balancing was difficult for some subject since movement of the diaphragm must be accomplished without straining or exerting pressure on the air held in the lungs. Also the extent that blood shifts affect the volume/signal relationship is not known at this time.

Figure 3 shows one of the more successful runs. The expiration tidal volumes of all the breaths as recorded by the magnetometer are plotted against the same volumes determined spirometrically.

The influence of the position of the subject (sitting or supine) on the accuracy of the magnetometer output is shown in Figures 4 and 5. In the supine position the accuracy was consistently better than in the sitting position.

Maintaining the latter for a longer period of time frequently results in forward or backward leaning of the subjects. It was found that the thoracic signal decreased when the subjects leaned forward.

Added respiratory resistance did not influence the accuracy of the magnetometer response, as demonstrated in Figures 6a, b, and 7a and b. The inspiratory resistances used in the tests are listed in Table I.

Figures 8 and 9 show the excellent accuracy of the magnetometer measurements in recording simultaneously minute volume, tidal volume and respiratory rate at high levels of respiration induced by CO_2 inhalation.

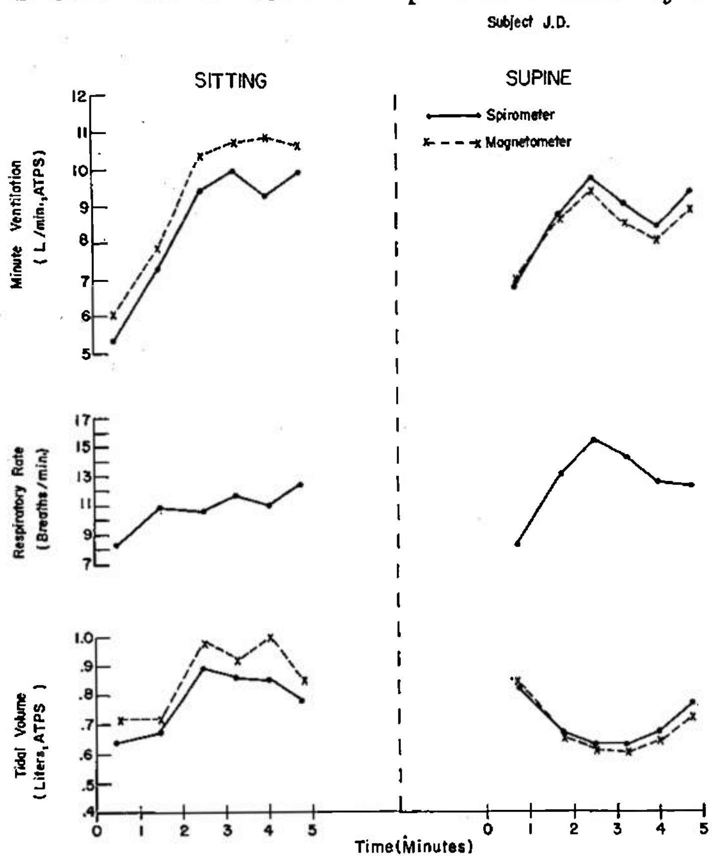

Fig. 4. Minute Ventilation, Respiratory Rate and Tidal Volume Plotted against Time into the Run. Each point represents the mean value over the period of one spirometer cycle. Respiratory rate will be the same on both records. This subject (J.D.) balances well, but errors are introduced by slight changes in posture. Other earlier runs on J.D. in the sitting position show tendencies to drift both above and below the standard, depending on posture changes.

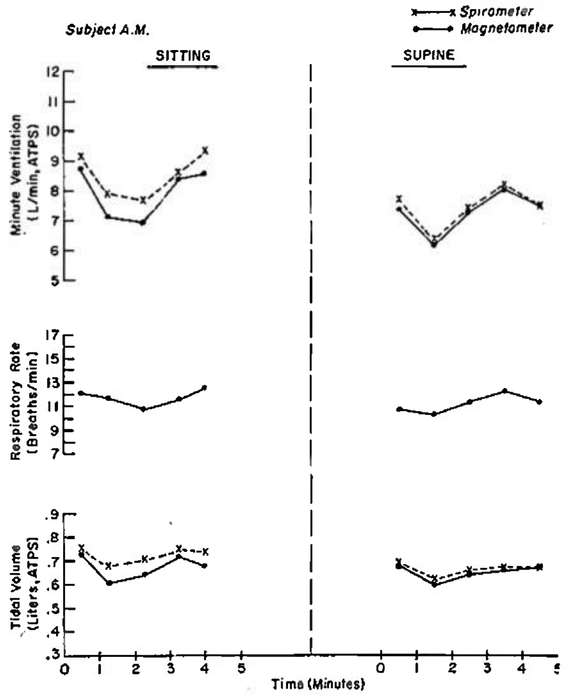

Fig. 5. Same as Figure 4, subject AM. The supine run was excellent, see Figure 3.

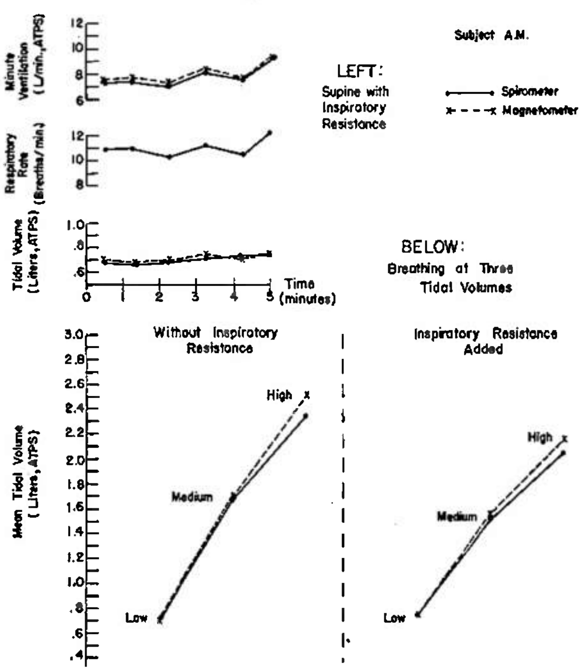

Fig. 7a. <u>Effects of Inspiratory Resistance.</u> Subject AM. and 7b. As with subject JD, the effect of the added resistance is not noticeable. Deviation of the data at tidal volumes greater than 2 liters appears unrelated to mild resistances. Balancing for many subjects is only exact at one inflation level. This causes errors at larger tidal volumes when the breathing pattern is altered.

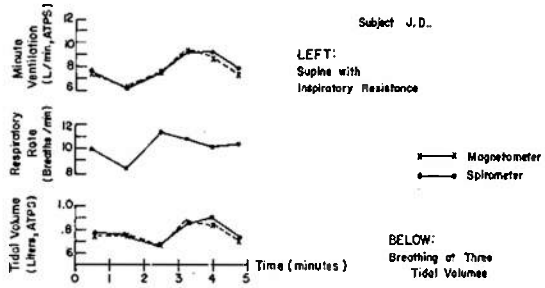

Fig. 6a. <u>Effects of Inspiratory Resistance.</u> The graph above shows the results of a 5-minute run with the inspiratory resistance added. Subject JD.

Fig. 6b. <u>Effect of Increasing Tidal Volume.</u> This causes changes in flow rates and respiratory pressures and effects on accuracy. For this sequence a single balance setting and calibration was possible. The separation of the thorax coils for subject JD is less than for other subjects, giving a stronger signal. Balancing at FRC also gives excellent results for larger tidal volumes.

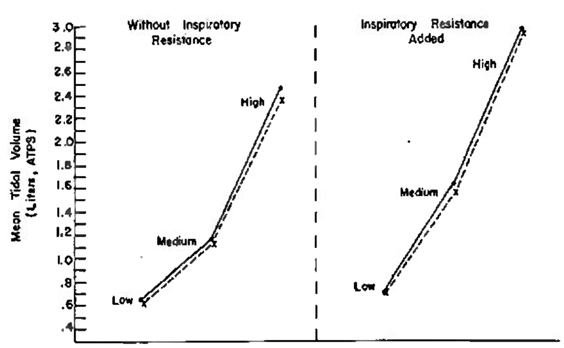

Table I. Inspiratory Resistance Used in Testing

Flow L/min	Expiratory Resistance mm H_2O L/min	Inspiratory Resistance mm H_2O L/min	With Extra Inspiratory Resistance Added mm H_2O L/min
50	0.02	0.01	0.01
100	0.06	0.02	0.03
200	0.20	0.06	0.30

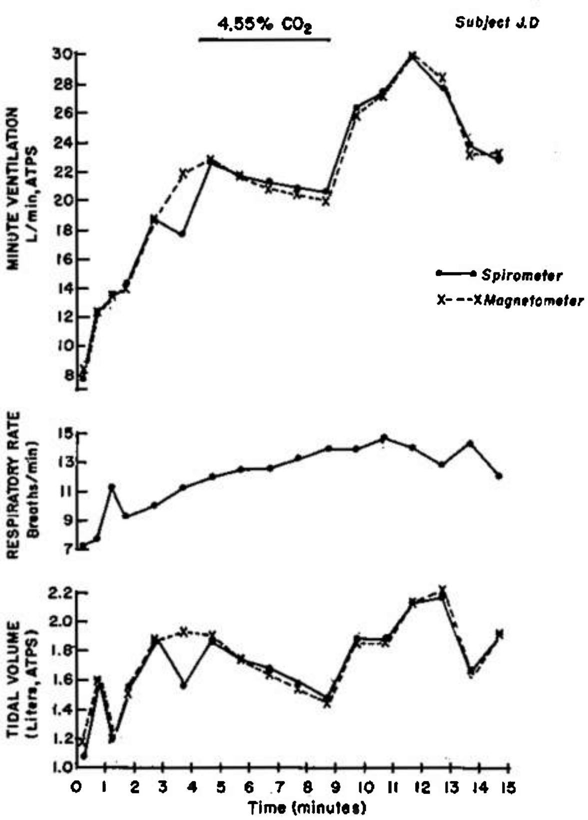

Fig. 8. Minute Ventilation, Respiratory Rate and Tidal Volume Plotted against Time into Run for Subject Supine with 4.55% CO_2 Supply Mixture. Subject JD. Here the ventilation is increased while the subjects are not moving. Again the balancing was correct and the results excellent. The stray point in the sixth cycle is the result of several coughs. These were noted at the time and were also easy to recognize on the trace.

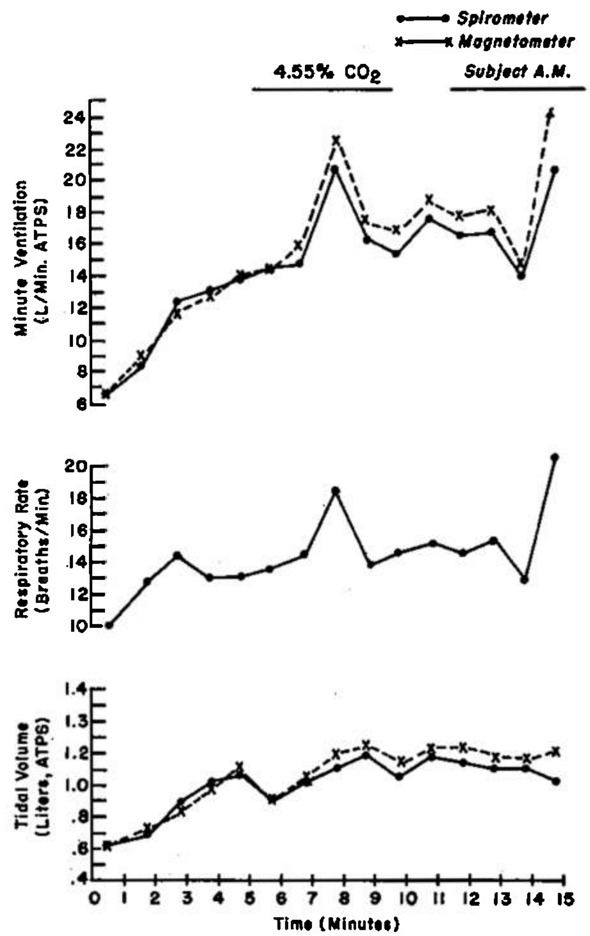

Fig. 9. Same as Figure 8, subject AM. The error seems to result from incorrect balancing at greater tidal volumes.

CONCLUSIONS

The magnetometer is capable of monitoring lung volume with remarkable accuracy in immobile, supine subjects. While precision is not possible for mobile subjects, the method is recommended for measuring respiration of subjects in the supine position during prolonged experiments at normal atmospheric and hyperbaric conditions. Freedom from the physiological load imposed by a mask, mouthpiece or neck seal enables the subject to breathe naturally and represents an important advantage for long term experiments. Since this technique is not sensitive to changes in temperature, pressure, or gas composition, it may be used in hyperbaric chamber experiments.

These areas need major improvements: (1) A rapid method of calibration that provides several determinations of volume for each signal level must be developed, (2) An analog data reduction circuit to automatically convert the changing volume signal to minute ventilation and tidal volume readouts would eliminate the need for reading each individual breath. An FM data tape recorder should be used to record the independent thorax and abdomen signals. With the whole system in operation a calibration maneuver would be recorded immediately prior to a given run and the data reduction circuit calibrated during tape playback. When calibration was accurate, the run would be played into the computing circuit and ventilation data in its final form would be displayed by a chart recorder. Manipulation of the analog circuit would take only a few minutes and taped data could never be lost due to inadequate calibration. Analysis time would be roughly equivalent to run time. In the work reported here, time consumed in analysis was about ten times the duration of a given run.

REFERENCES

1. Mead, J., N. Peterson, G. Grimby, and J. Mead. Pulmonary ventilation measured from body surface movements, Science. 156:1383-4, 1967.

2. Konno, K., and J. Mead. Measurement of separate volume changes of rib cage and abdomen during breathing, J. Appl. Physiol. 22:407-22, 1967.

3. Miller, W., T. Parrot, J. Dougherty, Jr., and K. E. Schaefer. Magnetometer respirometer for laboratory and diving studies, SMRL Report No. 69-4, 16 June 1969.

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13. ABSTRACT

A model of a respiration magnetometer, similar to one described by Mead, was constructed at the Submarine Medical Research Laboratory in Groton, Connecticut, by Parrot and Miller and has been modified recently for greater reliability and ease of operation. Good correlation between output signal and lung volume was found with supine subjects giving the most consistent results. The advantage of operation without mouthpiece, mask, or neck seal, and the instrument's insensitivity to environmental changes, make it particularly promising for prolonged studies of gas exchange and for hyperbaric research. A system for streamlined calibration and data reduction is proposed.

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