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VARIABILITY OF THE VITAL CAPACITY OF THE NORMAL HUMAN SUBJECT

By J. N. MILLS

Fellow of Jesus College, Cambridge

From the Department of Physiology, University of Cambridge

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Variations in the vital capacity (v.c.) in different physiological conditions, in health and disease, and between one subject and another, have frequently been recorded. The variations in one subject under supposedly identical conditions seem, however, to have received little attention. A study has therefore been made of control determinations obtained in the course of other investigations.

METHODS AND SUBJECTS

Seventeen healthy male subjects, aged 18–33 years, were used.

Respiratory tracings of v.c. and other determinations were obtained with a Krogh spirometer, and measured to the nearest 10 c.c. All volumes were corrected from spirometer water temperature to 37° C., the assumed temperature in the lungs. To test the supposition that expired air at once assumes the spirometer temperature, the lungs were on several occasions emptied rapidly into the spirometer through a tap, which was immediately closed. Any subsequent cooling of the air would cause a fall in volume, but such shrinkage was never more tham 20 c.c., which is very near the limit of accuracy of the measurements. The conditions in the lungs are much more favourable for thermal equilibration than are those in the spirometer circuit, so it seemed safe to assume that inspired air would promptly reach 37° C. It was also assumed that the air was always saturated with water vapour.

Before measurement of a series of v.c. the subject lay supine on a flat couch for 15 min., and an interval of at least 1½ min. separated successive determinations. This interval should be adequate, as Peabody & Sturgis (1921) carried out measurements at 15 sec. intervals for 10 min., with no progressive change such as might occur with fatigue.

Subjects were given practice at filling and emptying the lungs before any measurements of v.c. were made, and were encouraged to make smooth rather than jerky movements. They were allowed to take their own time, which was usually 15–20 sec. They sometimes supposed that assistance could be obtained by such procedures as bracing the elbows against the couch, or the feet against the lower surface of a table. Such manoeuvres were not usually allowed, but when they were permitted and the effect measured it did not appear that they gave any advantage.

The v.c. was taken as the maximal amount of air which could be expired at the end of a maximal inspiration, or inspired at the end of a maximal expiration.

The statistical techniques used are those of Fisher (1941).

RESULTS

Normality of distribution

Despite preliminary practice eight subjects recorded low values for the first two to six determinations of their v.c., later attaining values greater by from 200 to 600 c.c. Such series were disregarded for statistical analysis. Two of these subjects were each re-examined on 2 subsequent days, and now recorded a steady volume for their v.c.

Apart from these series there was always among the measurements made upon one subject on one occasion a scatter which appeared symmetrical, that is, occasional high figures were as frequent as occasional low ones, and the

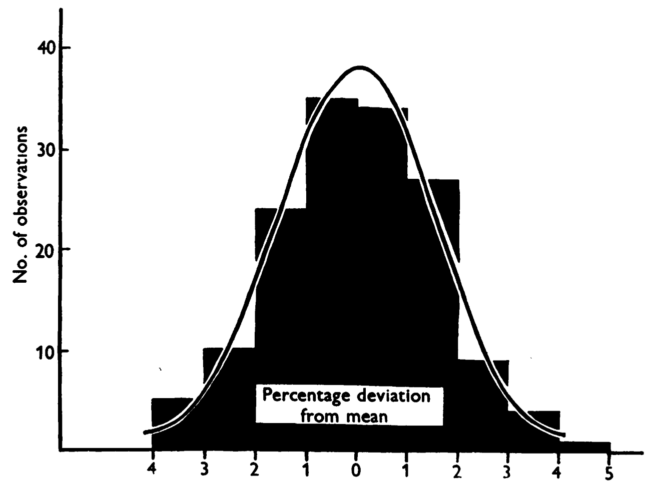

Fig. 1. Distribution of 149 determinations of the vital capacity upon subject P. upon 5 days. Values expressed as a percentage of the mean value for the day in question.

distributions appeared to be approaching normality. A formal test for the normality of distribution of separate determinations on one day has been performed on the subject P., for whom 149 measurements were obtained on five visits. Unfortunately, the means differed significantly from day to day, between 4590 and 5030 c.c., so the values have been calculated as a percentage of the mean for the day in question, and the resulting distribution is shown in Fig. 1. It will be seen that this distribution corresponds closely to the superimposed normal curve, calculated to have the same S.D. and total area, that is, number of observations.

If the distribution were really such that values considerably above the mean were rarer than those correspondingly below the mean, the cubic parameter γ_1 should be negative. The statistic g_1 is, however, $-0{\cdot}042 \pm 0{\cdot}200$, not significantly different from zero, and the distribution is therefore symmetrical.

In fifty-six series of at least ten determinations, upon seventeen subjects, standard deviations of from 45 to 293 c.c. have been found; and whilst some subjects appear more variable than others, the full range of values has been encounted upon J.N.M. The high values were all in the earlier series, and recent figures have usually been below 100 c.c.

Variability of inspiratory and expiratory depth

To find whether the variations in v.c. were due to varying depth of inspiration or of expiration, the subject expired maximally into the spirometer, connected to a circuit with a total volume of about 8 l., and then inspired maximally; still connected to the spirometer, he breathed quietly for $1\frac{3}{4}$ min., and then again expired and inspired maximally. In other experiments the sequence was maximal inspiration—maximal expiration—quiet breathing—maximal inspiration—maximal expiration. From each tracing two values for the v.c. were thus obtained, and a series of usually ten such tracings was recorded. The series was discarded unless the initial and final series of v.c. were similar in mean and variance.

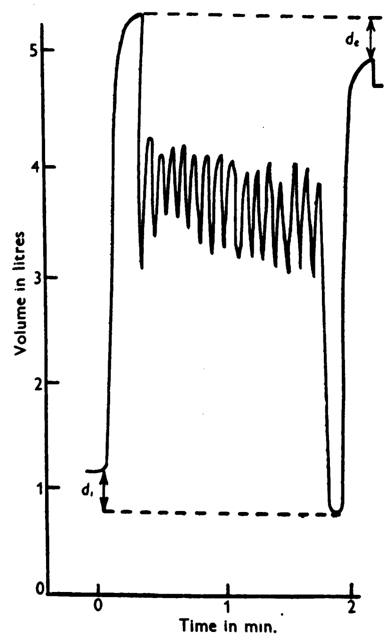

Fig. 2. Spirogram of two successive vital capacity determinations with an interval of $1\frac{3}{4}$ min., to illustrate procedure and terminology used. d_i, diminution of air volume in spirometer between the two maximal inspirations. d_e, diminution of air volume in spirometer between the two maximal expirations. Expiration upwards.

Fig. 2 shows one of the tracings obtained. Between the two measurements of v.c. some air was lost by respiratory exchange, so the volume recorded for the final maximal expiration or inspiration was less than that for the initial one by an amount designated d_e and d_i respectively. Their means must be equal. If, however, the variation of v.c. is due primarily to varying depth of inspiration or of expiration, the variance of d_i should be considerably greater or less than that of d_e, unless the variation in both is obscured by a very variable air loss through respiratory exchange.

In seven series upon J.N.M. the mean loss of air by respiratory exchange, d_i or d_e, was between 150 and 330 c.c., values which agree well with the respiratory air loss found by rebreathing quietly from the same spirometer circuit for $1\frac{3}{4}$ min. The S.D. of d_i was 150–320 c.c. and of d_e 24–66 c.c., that is to say, maximal inspiration was much more variable in depth than was maximal expiration. The P value for the ratio of variances in six series was below 0·001 and in one was between 0·01 and 0·001.

Variances similar to those of d_e and d_i respectively were found in series of recordings of two successive maximal expirations or inspirations separated by a few seconds of respiratory relaxation.

Nine other subjects were examined less thoroughly. In two maximal inspiration was significantly more variable than maximal expiration, in one a similar result was doubtfully significant ($P \simeq 0{\cdot}05$), and in six both were equally variable.

Day to day variation

Some series were of the inspiratory v.c., that is, the maximal volume of air that can be inspired after a maximal expiration, and some of the expiratory v.c., and it might be supposed that the inspiratory values would be somewhat greater, since respiratory exchange with a respiratory quotient of less than unity will cause loss of air from the lung-spirometer system during the determination. Upon four occasions with two subjects, inspiratory and expiratory determinations were made alternately, and the mean of the expiratory exceeded the mean of the inspiratory values by 3 ± 29 c.c. (S.E. of difference of means of two series of ten observations each), by 69 ± 71 c.c. (10, 10), by 34 ± 23 c.c. (20, 20) and by -6 ± 32 c.c. (20, 20). It thus appears that any such difference is insignificant.

TABLE 1. Analysis of variance of vital capacity in control determinations, expressed in centilitres

	Degrees of freedom	Sum of squares	Variance	P*
	Subject J.N.M.			
Between series:				
Due to linear regression on time	1	262,590	—	—
Due to deviations from linear regression on time	32	84,830	2,651	<0·001
Total	33	347,420	10,528	<0·001
Within series	314	85,530	272	—
Total	347	432,950	—	—
	Subject P.			
Between series:				
Due to linear regression on time	1	16,830	—	—
Due to deviations from linear regression on time	3	4,350	1,450	<0·001
Total	4	21,180	5,295	<0·001
Within series	144	8,500	59	—
Total	148	29,680	—	—
	Subjects Fo., Fr., L., Pa., R. and T.			
Between series upon the same subject	8	4,221	528	<0·001
Within series	206	26,365	128	—

* Probability that variance is really identical with that within series.

When two or more series of determinations were made on the same subject a few days or weeks apart, their means often differed significantly, and tended to increase. Analyses of variance, shown in Table 1, were therefore carried out on the two principal subjects (J.N.M., 348 observations in thirty-four series;

P., 149 observations in five series), including regression analysis on time in days. A similar analysis of variance of the pooled data on six other subjects (215 observations in fourteen series) is also included in the table. It will be seen that the differences between series are highly significant compared with the differences between observations within series. The differences between series consist of two components, a linear regression on time and deviations from linear regression, both highly significant. This means that there was a significant tendency to steady increase of v.c. with time (accounting for about three-quarters of the variation between series) and also a significant and as yet unexplained day-to-day variation in v.c. which is independent of time. With both subjects there was a small but significant negative correlation between v.c. and room temperature, but the fitting of partial regression functions on time and temperature did not greatly reduce the residual variance from regression.

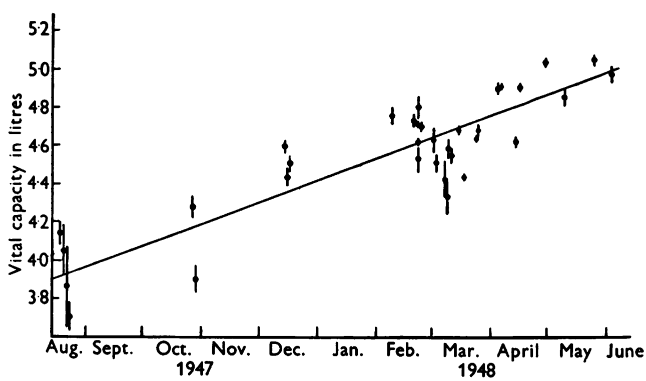

Fig. 3. Subject J.N.M. Mean vital capacity on different dates, with E.S.D. of each mean indicated by vertical strokes, and linear regression of vital capacity upon date inserted.

The steady rise of v.c. in J.N.M., about 1 l. in 9½ months, is shown in Fig. 3. P.'s v.c. increased by about 450 c.c. over an 18-day period.

DISCUSSION

Very few figures have been found which show the normal variation in v.c. determinations on one subject. Christie (1932) states that even under carefully controlled conditions duplicate determinations may differ by several hundred c.c. Sjöstrand (1941) has published a series of fifty-five triplicate determinations upon two subjects under a wide variety of conditions, and the S.D. calculated from his pooled results is 56 c.c., but the temperature and pressure at which his volumes are expressed is not stated. Gilson & Hugh-Jones (1949) have found a S.D. of between 85 and 140 c.c. in five normal and seven abnormal subjects. These figures are very similar to those here reported, and the narrower range may be due to the smaller number of series of observations.

The determinations upon one subject on one occasion are normally distributed, as was also found by Gilson & Hugh-Jones, and there is thus no indication that the larger values approach any maximal value which could be described as the 'true' v.c. The lungs are apparently stretched sometimes more, sometimes less, by more or less effective muscular efforts. There is thus no rational justification for publishing the result of two or more determinations as the maximal instead of the mean value, as West (1920), for example, has done, unless a progressive increase in volume suggests improvement with practice.

With J.N.M. the random variation is much greater for maximal inspiratory than for maximal expiratory efforts, and there is some indication that the same is true with some other subjects. Several authors (Christie, 1932; Hurtado & Boller, 1933; Gilson & Hugh-Jones, 1949) have commented upon a different variability in the reserve or complemental air, but unless the tidal air remained constant these observations do not necessarily represent variations in the depth of maximal expiratory or inspiratory efforts. The objective evidence is at complete variance with the subjective impression, that when expiring maximally it is usually possible to expel a little more air by an even more powerful effort, but that when inspiring maximally one reaches a fixed point beyond which no more can be inspired.

A progressive increase of v.c. with time, here observed in two subjects, was also noted by Gilson & Hugh-Jones, and suggests a slow improvement with repeated practice, even over a considerable period of time. The quite large residual variance from regression might be due to variations in pulmonary congestion, through variations in vasomotor tone in the systemic circuit. Varying degrees of distension of the abdominal viscera are not likely to be responsible, as most series of determinations were performed at about the same time after a similar breakfast, and Mills (1949) has shown that considerable abdominal distension has little effect upon the v.c. The occurrence of such day to day variation stresses the need for adequate control of all observations upon alterations in v.c.

SUMMARY

1. Sixty-two series of control determinations of the vital capacity have been performed upon seventeen subjects, comprising 839 separate determinations. Upon any one subject on any one occasion, the values are normally distributed, with unusually high values as frequent as unusually low ones. The S.D. usually lies between 50 and 200 c.c.

2. The variation in one series is due to more or less successful muscular effort, and the maximal inspiratory effort is often more variable than the maximal expiratory effort.

3. Variance analysis shows a considerable day to day variation in the v.c. outside the variation to be expected on one occasion. In the two subjects

repeatedly examined, there has been a continuous increase, extending in one subject over 9½ months and amounting to about 1 l.; variance from regression on time is, however, highly significant.

My thanks are due to those who have acted as subjects for these experiments, and to Mr S. Langford for technical assistance.

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