EXPERIENCE WITH THE RANDOM-ZERO SPHYGMOMANOMETER

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SOURCES of variation and bias in the measurement of blood pressure with a sphygmomanometer have been identified in the observer, the subject, and the instrument (Rose, Holland, Crowley, 1964). Systematic and non-systematic variation in measurement, which clinicians may be content to ignore, can attain importance in research by vitiating between-group comparisons through variable bias or necessitating inconveniently large samples or frequent measurements.

Machines are available for automatically recording indirect blood pressure measurements in the laboratory. The epidemiologist is at a disadvantage compared with laboratory workers, in that he may require a machine which is portable and robust, and can take measurements quickly. Two modified sphygmomanometers are available which fulfil these criteria. The London School of Hygiene and Tropical Medicine Sphygmomanometer (Rose *et al.*, 1964) reduces several types of error and has been extensively tested in epidemiological studies (Humerfelt, 1966; Eilertsen and Humerfelt, 1968). In the particular circumstances of our field work in the South-west Pacific, we have found this instrument inconvenient owing to its bulk and weight and the difficulty of servicing it in the field. We have recently tested a simpler instrument, the random-zero sphygmomanometer (Wright and Doré, 1970). For convenience in this report we shall use the title 'zero-muddler', as applied to earlier instruments based on the same principle (Garrow, 1963; Miall, 1967). Although designed primarily for epidemiological work, this instrument would be of use in

clinical situations where an observer has an expectation of what a blood pressure is likely to be.

THE INSTRUMENT

The zero-muddler (Figure) is essentially a sphygmomanometer modified so that the true zero level can be varied unpredictably between a scale reading of 0 to about 70 mm. The observer does not know what the current zero level is until after he has taken a blood pressure reading. The instrument has a taller wide arm and larger mercury capacity than the conventional sphygmomanometer. Attached to the system is a variable capacity reservoir into which mercury can pass under the pressure of inflating the sphygmomanometer cuff and then be excluded from the system by the turning of a tap. The capacity of the variable reservoir is determined by its point of impingement on a helical surface. By spinning this surface the operator sets a new unknown zero for the subsequent measurement.

To take a reading, the operator ensures that the reservoir tap is open and the mercury drained into the main system. He then spins the helix-controlling wheel and raises the cuff pressure to a scale reading of 200mm., or higher if indicated by palpation of the radial pulse. He then turns the tap excluding the mercury-filled reservoir from the main system, and measures the blood pressure, noting the scale readings in the usual way. On disconnecting the cuff, the mercury column falls to a level determined by how much has been excluded in the reservoir. This level is the zero-correction, which must be subtracted from the original scale readings to give the

actual blood pressure measurements. The system incorporates a valve which offers some resistance to the movement of mercury when the cuff is being inflated, but opens freely as the cuff pressure falls. This gives the reservoir time to fill, and also prevents the observer from deducing whether a large or small zero-correction is involved from the change in mercury movement as the reservoir fills.

FIGURE. The random-zero sphygmomanometer. The wheel used to spin the reservoir-controlling helix protrudes through the slot on the right-hand side of the case. The reservoir tap is seen on the front of the instrument to the left of the scale.

A further refinement of the machine is a valve intended to provide a constant rate of lowering of cuff pressure. Since the main object of this study was to search for systematic differences between sphygmomanometer and zero-muddler attributable to the use of a 'blind' zero level, the valve was bypassed for all the measurements reported. Our subsequent experience has been that the valve is difficult to control and erratic in use, at least after exposure to tropical conditions.

METHODS

The blood pressure of each subject was measured twice by the same observer, once with the zero-muddler, and once with the conventional sphygmomanometer following the technique recommended by the American Heart Association (1967). A 14-cm. cuff was placed on the subject's arm and connected to the two instruments in turn. The order in which the instruments were used was randomized. Two observers took part in the study. One observer (A) rounded to the nearest even number of millimetres of mercury, the other (B) read to the nearest millimetre. The results from the two observers bearing on the comparison of the two instruments were similar and are not presented separately in detail.

The majority of subjects were participants in epidemiological field studies in Ruatahuna, New Zealand, and the Tokelau Islands. Other subjects were patients and staff of Wellington Hospital. All pressures were taken on the right arm using a constant technique, but no attempt was made to bring subjects to a "steady state". In the field studies, one observer (B) was taking mostly paired measurements of "casual" blood pressures with the subject seated. These were taken following an explanation of the procedure and a demonstration inflation and deflation of the arm cuff. The other observer (A) saw the same subjects up to two hours later and took paired measurements in the course of a general physical examination with the subject lying down. Two zero-muddlers were used: preliminary studies showed no evidence of difference in performance between them, and their readings have been pooled. Fourth phase diastolic pressures are reported.

Three ordinary sphygmomanometers of different makes were used during the study. These were checked for consistency by being connected in pairs to a common pressure source. The scale readings did not differ by more than 1 mm.

After the main study was completed, observer B made a further 236 paired observations of seated casual blood pressure during a field study in Rotorua, New Zealand. The method used was as before, except that, before reading the zero-correction, the zero-muddler was tilted briefly about 10° towards the right (that is towards the wide arm) and then returned to the vertical position. The zero-correction was then read after a pause of at least 5 seconds to allow the masking valve to disengage and the mercury to equilibrate.

RESULTS

A total of 906 pairs of readings were taken on 587 different subjects—472 participants in field

surveys and 115 hospital patients and staff. Three hundred and eighty four of the pairs of observations were made by observer A and 522 by observer B. In 448 of the observations the sphygmomanometer was used before the zero-muddler, and 458 observations were made in the reverse order.

The zero-muddler was simple to use and no more tiring than the conventional instrument, but was somewhat slower. Some subjects observed spontaneously that the cuff was tighter and inflated longer for the zero-muddler than for the sphygmomanometer. No serious complaint was raised, even by nervous and medically-unsophisticated subjects.

Both observers showed a high correlation between pressures measured with the two types of instrument. The correlation coefficients for systolic pressure were 0.93 for observer A and 0.95 for observer B, and for diastolic pressure 0.85 for A and 0.92 for B.

TABLE I
MEANS AND STANDARD DEVIATIONS OF OBSERVATIONS
ACCORDING TO INSTRUMENT AND ORDER OF USE

	No. of Observations	Systolic		Diastolic (4th phase)	
		Mean	S.D.	Mean	S.D.
Sphygmomanometer					
Total	906	134.4	26.0	82.3	15.6
Used first	448	136.0	26.9	82.3	15.4
Used second	458	132.9	24.9	82.4	15.8
Zero-muddler					
Total	906	133.3	26.3	80.2	16.5
Used first	458	134.2	27.0	79.4	16.8
Used second	448	132.4	25.5	81.1	16.2

Table I summarizes the means and standard deviation of the observations made with the two

TABLE II
PERCENTAGE DISTRIBUTION OF 906 SYSTOLIC READINGS
BY TWO INSTRUMENTS

	Sphygmomanometer (%)	Zero-muddler (%)
80-99	4.0	5.1
100-119	27.0	30.2
120-139	35.6	33.4
140-159	20.1	18.2
160-179	7.3	7.1
180-199	3.1	3.3
200-219	1.8	1.4
220-239	0.8	0.9
≥ 240	0.2	0.3
Total	99.9	99.9

types of instrument according to their order of use. For both instruments "first" readings of systolic pressure tend to be higher than "second". For diastolic pressure "second" readings are similar to or higher than "first". There is a tendency for the zero-muddler to read lower on average than the sphygmomanometer and this difference is greater for "first" readings than for "second". The variance of zero-muddler readings is insignificantly higher than those of the sphygmomanometer. Tables II

TABLE III
PERCENTAGE DISTRIBUTION OF 906 DIASTOLIC
READINGS BY TWO INSTRUMENTS

	Sphygmomanometer (%)	Zero-muddler (%)
< 50	0.2	1.3
50-59	2.8	5.2
60-69	15.6	19.2
70-79	29.8	29.9
80-89	28.0	21.6
90-99	12.5	13.3
100-109	5.2	4.5
110-119	2.8	2.1
120-129	1.7	1.4
130-139	0.9	0.8
≥ 140	0.6	0.7
Total	100.1	100.0

and III show the distributions of the observations by the two instruments. Table IV presents means and standard deviations of the within-paired

TABLE IV
MEANS, STANDARD DEVIATIONS, AND STANDARD
ERRORS OF THE DIFFERENCES BETWEEN PAIRED
READINGS BY THE TWO INSTRUMENTS (SPHYGMO-
MANOMETER READING MINUS ZERO-MUDDLER
READING) (906 OBSERVATIONS)

	Mean	Standard Deviation	Standard Error
Systolic	1.20	8.50	0.28
Diastolic (4th phase)	2.18	7.30	0.24

observation differences between the two types of instrument. This table confirms the suggestion from Table I that the zero-muddler readings were slightly but significantly lower than those of the sphygmomanometer. Table V shows the distribution of the within-pair differences according to the order in which the instruments were used.

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TABLE V

PERCENTAGE DISTRIBUTION OF DIFFERENCES BETWEEN SPHYGMOMANOMETER AND ZERO-MUDDLER READINGS ACCORDING TO ORDER OF USE

	Order of Instrument	No. of Observations	Differences (mm. Hg)							Total
			≤ -26	-25 to -16	-15 to -6	-5 to +4	5 to 14	15 to 24	25-34	
Systolic	Sph.	448	0.2	0.9	8.9	46.9	34.8	7.6	0.7	100.0
	ZM Sph.	458	1.8	3.7	19.2	53.3	20.3	1.8	—	100.1
Diastolic	Sph.	448	—	0.9	15.6	55.8	24.6	2.9	0.2	100.0
	ZM Sph.	458	0.2	—	7.9	52.6	34.7	4.2	0.4	100.0

Table VI shows the distribution of the zero-muddler corrections recorded. The bias towards higher values is partly due to observer technique. In the earlier part of the study both observers were allowing insufficient time for the mercury reservoir to fill before closing the tap. Care was taken over this in the later readings by making a definite pause at the point of maximum inflation before closing the reservoir tap.

Table VII shows the distribution of terminal digits recorded by the two observers for the sphygmomanometer and zero-muddler readings and for the zero-muddler corrections. Observer A, reading to the nearest even number of millimetres, shows a slight bias against eight in the sphygmomanometer readings. His attempted reading of the zero-muddler correction to the nearest millimetre shows a strong preference for even digits, which is also seen in the corrected readings from the instrument. Observer B, reading to the nearest millimetre, shows a slight preference for even digits generally, and a bias against terminal digits of one and five. His preference for even terminal digits, especially zero, emerges in his reading of the zero-muddler correction, but is largely obscured in the final blood pressure readings from the instrument.

For the 236 paired readings of the second study, in which the zero-muddler was tilted briefly before the correction was read, there was a tendency for the

TABLE VI
PERCENTAGE DISTRIBUTION OF ZERO-MUDDLER CORRECTION IN MILLIMETRES OF MERCURY (906 READINGS)

mm. Hg.	%
0-9	1.2
10-19	5.5
20-29	12.3
30-39	18.3
40-49	22.3
50-59	19.9
60-69	17.5
≥ 70	3.0

sphygmomanometer readings to be *lower* than those from the zero-muddler. The mean difference was -0.68 (S.E. 0.43) for systolic and -0.63 (S.E. 0.31) for fourth phase diastolic pressures. The mean difference for diastolic pressures is significantly different from zero ($P < 0.05$).

DISCUSSION

The zero-muddler may be expected to obscure terminal digit preference, and also to make it possible for a single observer to take repeated independent blood pressure measurements on the same subject. Only the systolic readings will be strictly "blind" in this situation, since the observer's knowledge or expectation of the pulse pressure might affect his diastolic reading. As shown in Table VII the instrument can effectively obscure terminal digital preference, except when this consists of a

TABLE VII

DIGIT PREFERENCE BY TWO OBSERVERS IN BLOOD PRESSURES (SYSTOLIC PLUS DIASTOLIC READINGS) MEASURED BY TWO INSTRUMENTS AND IN READING THE ZERO CORRECTION

	No. of Observations	1	2	3	4	5	6	7	8	9	0
Observer A Sphygmomanometer	768		18.9		21.7		21.5		17.5		20.3
	768	4.0	13.4	3.9	13.5	4.9	17.7	4.3	18.0	5.0	15.3
	384	4.3	16.8	4.5	17.0	4.3	14.8	4.8	14.2	3.4	15.9
Observer B Sphygmomanometer	1044	4.2	10.9	10.5	12.0	6.9	13.0	8.1	10.6	11.4	12.5
	1044	10.1	10.8	8.3	10.3	10.7	9.7	8.7	11.8	9.2	10.5
	522	4.8	12.8	5.6	12.1	6.1	10.9	7.3	17.0	3.6	19.7

strong even-odd bias. A preference for the same digit in both the initial readings and the correction might lead to an increased proportion of zeros in the corrected pressures. To have an important effect, such a preference would need to be strong, unless there was also a within-observation correlation between the terminal digits of initial reading and correction. Where there is no digit preference in either initial reading or correction, the chance of obtaining a zero when one is subtracted from the other is 0.1 where readings are to the nearest millimetre. With a digit preference such that 19% of readings end in one digit, and only 9% in each of the others, the probability of obtaining a zero on subtracting one uncorrelated reading from another would be increased only to 0.109.

The price for this smoothing out of digit preferences lies in an increased variance of the zero-muddler pressures arising from the error variance in reading, rounding and subtracting the correction. In our data, as shown in Table I, the increase was small compared with the total variance.

In order to fill the mercury reservoir the cuff pressure may have to be higher and maintained longer in the zero-muddler than in the ordinary sphygmomanometer. This might be expected to cause a slight increase in pressures read by the newer instrument. In this study the zero-muddler seems to read slightly lower than the conventional sphygmomanometer (Tables I and IV). This difference does not vary significantly from systolic to diastolic readings, and is probably somewhat less than 2 mm. of mercury. Two factors may contribute to this difference, one a consequence of the experimental design and one a matter of observer technique and the nature of the zero-muddler.

First, taking a blood pressure with a zero-muddler is somewhat slower than when using a sphygmomanometer. The subject, therefore, has a longer time to react to the procedure when the zero-muddler is used for the first of the two readings than when the sphygmomanometer is used first. As subjects were not brought to a steady state the two instruments would sample from different sets of "first" blood pressures. Owing to habituation this effect may be expected to be less pronounced when the second readings are taken, which will give a better estimate of the difference between the two instruments when the subject is in a steady state. The differences between the mean readings of the two instruments when used first were 1.8 (S.E. 1.8) mm. for systolic pressure and 2.9 (S.E. 1.1) mm. for diastolic pressure (Table I). Comparing observations for which the instruments are used second these differences fall to 0.5 (S.E. 1.7) mm. for systolic and

1.3 (S.E. 1.1) mm. for diastolic. These results are not statistically significant evidence for the presence of an interaction between type of instrument and order of use. They are, however, in the direction to be expected if such interaction were present and contributing to the observed differences between the readings by the two instruments. The reasoning used above is dependent only on the premise that second readings are taken nearer to a steady state than are first, and does not necessarily require that blood pressure trends over the period of measurement should be demonstrably linear. According to Table I, systolic pressure tended to fall from first to second reading with both instruments. With diastolic pressure it tended, if anything, to rise. For systolic pressures, therefore, a time trend seems a plausible contributor to the difference between instruments. For diastolic pressures, the corollary would be that the time trend was U-shaped, resulting in a fall during the phase when "first" blood pressures are measured but subsequently showing a nett rise before the "second" readings. Before dismissing this as implausible we would need to consider not only physiological factors but also the heterogeneity of the subjects studied.

The second factor producing a difference between the two instruments subsumes several influences tending to give an upward bias to the scale reading for the zero-correction. The mercury takes time to settle after disconnection of the cuff, and the reading may be taken too soon in a busy field situation. Any tendency for the mercury to stick to the glass will tend to bias the zero-correction upward as the mercury loses momentum near its equilibrium point. Parallax error may also contribute if the instrument is positioned like a conventional sphygmomanometer, that is with the observer's eye-level opposite the scale range in which systolic and diastolic pressures are likely to fall. We have been able to demonstrate biased reading of the zero-correction in laboratory studies by taking simultaneous readings on a zero-muddler and sphygmomanometer connected to a common cuff. Some zero-corrections were read higher by one or two millimetres than the difference between scale readings when the cuff was inflated over a wide range of pressures. From the results of the second study in Rotorua, it seems that an attempt to remove this effect by tilting the zero-muddler briefly before reading the zero-correction introduced a smaller bias in the opposite direction.

Mechanically, the two zero-muddlers stood up well to rough handling and to travel by aeroplane, ship and outrigger canoe in both temperate and tropical conditions. On one occasion a reservoir tap became

stiff, and on another the mercury "masking" valve jammed, but both defects were remedied easily in the field. The instrument has theoretical advantages over the conventional sphygmomanometer in epidemiological and some clinical situations. Its minor disadvantages include a prolongation of the period of cuff inflation and the need for care over details of technique, especially in reading the zero-correction. We have found it to be more portable, quicker and less tiring to use than the otherwise more desirable London School of Hygiene and Tropical Medicine sphygmomanometer.

From the subject's point of view, the zero-muddler is slightly less comfortable than the conventional sphygmomanometer, since the cuff may be inflated to a higher pressure and remain inflated longer. This difference caused occasional comment but no serious complaint.

SUMMARY

Experience in epidemiological studies with the random-zero sphygmomanometer is described. The instrument is robust and portable and has advantages over the conventional sphygmomanometer in that it reduces the effects of observer expectation of a blood pressure level and observer terminal digit preference. In the data reported the random-zero instrument read about 2 mm. of mercury lower on average than a conventional sphygmomanometer. Reasons for this are discussed.

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The random-zero sphygmomanometer is manufactured by Hawkesley and Sons Limited, 12 Peter Road, Lancing, Sussex, England.

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