A QUANTITATIVE DETERMINATION OF THE PERSONAL FACTOR IN BLOOD PRESSURE MEASUREMENTS BY THE AUSCULTATORY METHOD

COMPARISONS WITH OTHER METHODS *

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Much has been written with regard to errors in human blood pressure measurements connected with such factors as rigid arterial walls, a too narrow cuff, etc., or the choice of the criteria for determining when pulse waves begin to pass under the cuff or when the diastolic pressure is reached; but heretofore little attention has been paid to the personal factor which operates in the identification of the various criteria. Since it is the large amount of individual judgment involved in "guessing" blood pressure by feeling of arteries, which has led to the general adoption of instrumental methods, it is important to inquire, in addition to other sources of error, how large this personal element may be when blood pressure instruments are used. Oscillatory criteria both for systolic and diastolic pressure, which have been advocated for use with several highly authorized instruments and which have been widely accepted as the most accurate and freest from subjective error, have been shown to invite surprisingly large variations in interpretation.¹ The ordinary palpatory method for systolic determinations has been investigated from this point of view² and the present report deals with similar experiments applied to the auscultatory criteria for both systolic and diastolic pressure. The experiments were in three groups:

GROUP 1.—The "Two-Arm" Experiments: This group consists of experiments by two of us (K. and S.) on sixty-one candidates for admission to the university, all healthy young men from 16 to 32 years of age. During the course of the required medical examination the blood pressure determinations were made with the subject lying quietly on his back on a narrow table. A 12 cm. pneumatic cuff was fitted to each arm, and both cuffs were connected with the *same* mercury U-tube manometer, which was overhung so as to be equally readable from both sides of the table. Both cuffs were inflated simultaneously

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1. Kilgore, E. S.: Page 893, this issue.

2. Kilgore, E. S.: California State Jour. Med., March, 1914.

to a pressure above systolic pressure; and then, while the air from the combined system was gradually released through a slow outlet valve (the mercury falling about 2 mm. per second), one of us listened with a small open bell stethoscope over the artery a few centimeters below the cuff on the right arm while the other with a similar stethoscope ausculted at a corresponding point on the left arm. Each independently recorded by his reading of the manometer when the first sound was heard (systolic pressure), when the loud tapping sound finally changed to a dull distant one (the so-called "fourth phase" index of diastolic pressure), and when all sounds were lost ("fifth phase" index of diastolic pressure).³ After two such procedures on one side we changed sides and repeated. Whenever the reading was not clear on account of extraneous noise or other accident no result was recorded; but if the observation was unhindered and the reading not clear on account of doubt about the definiteness of the criterion, a question mark was recorded in place of the reading. In these as well as in later experiments care was taken to avoid unconsciously signaling to one's partner when readings were made.

In this group the differences between the simultaneous readings of two observers obviously may be due to two causes: 1. Differences in hearing and interpreting the sounds and in observing the corresponding positions of the mercury column. 2. Actual differences in the blood pressure in the two arms or differences in the size or position of the artery or in the adjusting of the cuffs and stethoscopes. In order to separate these factors and ascertain the discrepancies referable to each of them the following group of experiments was undertaken.

GROUP 2.—The "One Arm" Experiments: In this group of experiments by K. and S., sixty-six of the same class of subjects were utilized. The procedure was exactly the same as in the first group with the exception that only one pneumatic cuff was used and but one stethoscope with a Y connection and two pairs of ear pieces. With the two branches of the stethoscope tube of equal length and the manometer equally readable to both observers, it is evident that both made their readings from absolutely identical data and that the discrepancies occurring in this series are referable solely to the first cause mentioned

3. Discussions of the merits of these "phases" as indices of diastolic pressure will be found in the following articles: Korotkoff: *Mitth. a. d. mil. med. Akad. zu St. Petersburg*, 1905, xi, 365; Fischer: *Ztschr. f. diätet. u. phys. Therap.*, 1909, xii, 389; Lang and Mansivetona: *Deutsch. Arch. f. klin. Med.*, 1908, xciv, 441; Ettinger: *Wien. klin. Wchnschr.*, 1907, xx, 992; Gittings, J. C.: *Auscultatory Blood-Pressure Determinations*, *THE ARCHIVES INT. MED.*, 1910, vi, 196; Warfield, Louis M.: *Studies in Auscultatory Blood-Pressure Phenomena*, *THE ARCHIVES INT. MED.*, 1912, x, 258.

above. The discrepancies due to the second cause may then be determined by subtracting these results from the former ones.

GROUP 3.—The Control “One-Arm” Experiments: These were repetitions of the last group of experiments undertaken by the other two of us (B. and R.) as a control for the experiments of K. and S. The essential sameness of the results in the second and third groups counts toward the justification of the assumption that our results would correspond reasonably with those of others—an assumption formerly made by two of us in considering our results with the palpatory method.² The subjects in this group were twenty patients in the medical and surgical wards of the University of California Hospital. They were of both sexes and varied in age from 14 to 53 years and were without obvious cardiovascular abnormality. They were resting quietly on narrow hospital beds, and the manometer, which was a straight mercury tube and reservoir, was placed on a shelf over the bed. As an additional precaution against one observer’s influencing the other, in these experiments a screen was placed over the bed between them, and the inflation and deflation of the cuff was controlled by an assistant.

To facilitate comparisons and avoid bewildering columns of figures, the results have all been reduced to percentages and expressed graphically in Figures 1 to 9. The curves are all according to one plan, which is to show the discrepancies between the readings of two observers⁴ expressed in millimeters of mercury, and the percentage of instances in which each degree of discrepancy occurred. Millimeters of mercury are expressed along the abscissae and percentages of instances along the ordinates. Each curve except in Figure 7 extends both to the right and to the left of zero in order to show separately for each observer the instances in which his readings were the higher. Thus, a curve with long, lateral extensions and a blunt peak indicates that there were some large discrepancies and relatively few agreements, while a sharp tall peak with short lateral extensions signifies comparatively good results. A curve which reaches its highest point away from the zero pressure ordinate indicates a general tendency for one of the observers to choose higher reading points than the other. Perfect results would be represented by a peak reaching to 100 per cent. at zero mm. Hg.

In the first and second groups of experiments, in which a U-tube manometer was employed, there was a tendency for the readings and, hence, the discrepancies, to fall on the even numbers oftener than the odd, thus giving the plotted curve a “saw-edge” outline. Since irregu-

4. In one instance (Fig. 9) the marks of one individual made at two different times on duplicate graphic records are compared; and in Figure 7 the “fourth phase” and “fifth phase” readings of the same observers are compared.

larities of this dimension, when once their cause is recognized, have no further importance but interfere somewhat with the larger comparisons which it is desired to make, they have been "smoothed out," as will be observed, by combining values for the even and odd millimeters of mercury.

In the experiments in which the one divided stethoscope was used (Groups 2 and 3) the practical correspondence of the results by two pairs of observers is shown in Figures 1, 2, and 3. The solid lines show the differences between the readings of K. and S. and the dotted lines the same for B. and R.

In the systolic determinations (Fig. 1) the differences in the second group vary from zero to 12 mm. Hg and average 1.42; in the third group from 0 to 10 mm. Hg, average 1.58.

Fig. 1.—Close correspondence shown in results of two series of "one-arm" systolic readings. Solid line, discrepancies of K. and S.; dotted line those of R. and B. The cases in which K's readings and those of R. were higher than those of their partners are to the left side; to the right are the cases in which S's and B's readings were higher.

In the use of the change of sound or "fourth phase" diastolic criterion (Fig. 2) discrepancies in the second group occur as high as 15 mm. Hg and average 2.6; in the third as high as 9 mm. Hg, average 2.47.

In locating the points of sound disappearance (Fig. 3) K. and S. recorded points as far apart as 17 mm. Hg, and their average difference was 2 mm.; B. and R. had an average difference of 1.76 mm. Hg and once 10 mm.

It will be seen that there is essential uniformity in the results of the two pairs of observers both in the range and distribution of the discrepancies and in the averages. In view of this correspondence it is assumed that the showings made by K. and S. in the first and second groups of these experiments, as well as in their previously

reported experiments with the palpatory method² represent the errors referable to the personal factor which ordinarily prevail in the use of these methods. In the following analysis, therefore, only their results are included.

The Systolic Readings.—Taking as we did, as the index of systolic pressure, the first sound heard while air was escaping from the cuff, none of these points was classed as doubtful in any of the series of experiments. The beginning of the sounds was usually very clear cut,

Fig. 2.—"Fourth phase" diastolic readings. Arrangement same as in Figure 1, except that the higher readings of B. are to the left and those of R. to the right.

Fig. 3.—"Fifth phase" diastolic readings. Arrangement same as in Figure 1.

and we were surprised by some of the large discrepancies in our records. It seems probable that some of the wide variances here as well as in the diastolic determinations were due to mistakes of ten points in reading the manometer.

As previously indicated, disagreements in the second group of experiments in which but one cuff and one stethoscope were used can only be accounted for by errors in reading the manometer and in recognizing the criterion. These are shown in the solid line in Figure

4. The dotted line shows the discrepancies of the same observers when two pneumatic cuffs and two stethoscopes were used. The figure shows that in the "two-arm" experiments fewer of the discrepancies are near zero and more of them have higher values than in the "one-arm" group; the average in the former case being 3.54 mm. Hg and in the second 1.42. The difference of 2.12, as explained above, is a measure of the added effect of using both arms of the subject and applying two cuffs and two stethoscopes.

Fig. 4.—Systolic readings. Relation shown between discrepancies in simultaneous readings of K. and S. using one stethoscope (solid line) and the discrepancies of the same observers in the "two-arm" experiments (dotted line). The higher readings of K. are to the left, those of S. to the right.

Fig. 5.—"Fourth phase" diastolic readings. "One-arm" and "two-arm" determinations compared as in Figure 4.

These figures are based on 236 determinations (by each of two observers) in the sixty-one subjects of the first group, and 282 determinations on the sixty-six subjects in the second group. None of the readings were classed as doubtful.

The Diastolic Readings by the "Fourth Phase" Index.—Figure 5 is arranged in the same way as Figure 4 to show the comparative results when one stethoscope and when two were used. The average discrepancy in the one-stethoscope experiments was 2.6 mm. Hg, in the

first group 3.09, a difference of 0.49 mm. Hg. The smallness of this difference is partly explainable by the tendency of K. in the second group of determinations to choose a point 1 or 2 mm. higher than S. did; a tendency not observed in the first group of experiments and clearly due to a slight change during the course of the experiments in the habit of either S. or K. in interpreting the criterion.

Out of 232 attempted "fourth phase" readings in the first group only seventy-nine were accepted for the above analysis, the remaining 153 (66 per cent.) being classed as "doubtful." These occurred in fifty-five of the sixty-one subjects. Similarly among the 273 attempted readings in the second group 143 or 51 per cent. (occurring in fifty-seven out of the sixty-six subjects) were rejected as "doubtful."

"Fifth Phase" Diastolic Readings.—In the first group there were 228 of these readings and in addition four marked questionable; in the second group 260 readings and twelve which were discarded as doubtful.

Fig. 6.—"Fifth phase" diastolic readings. "One-arm" and "two-arm" determinations compared as in Figure 4.

Figure 6 shows that in the one-stethoscope experiments the results are comparable with those for the other criteria, and that the two observers took the higher readings about equally.

In the "two-arm" experiments the discrepancies are much larger than usual on both sides of the figure, which suggests that in these subjects at least the disappearance of sounds is particularly subject to variation from sources other than blood pressure, such, for example, as anatomic variations or variations in the adjustment of the apparatus.

The curve also shows, however, that a preponderance of the higher readings was made by S., that is, K. more often followed the sounds to a lower level. Since this difference does not appear in the "one-arm" experiments, the only possible explanation is that here again, during the course of the experiments, one at least of these observers changed his habit of interpreting the criterion.

Relation Between "Fourth Phase" and "Fifth Phase" Readings.—An opportunity is here afforded to compare the difference between "fourth phase" and "fifth phase" readings in two slightly different groups of subjects, hospital patients and young men students. Figure

7 shows this comparison in the two groups of experiments which were exactly parallel (the "one-arm" experiments) on the two classes of subjects. In each group the readings of both observers have been included; the solid line represents the differences between fourth and fifth phase readings when the students were used as subjects by S. and K., the dotted line represents the same differences in the readings of B. and R. on hospital patients. It will be noted that the greatest differences between these two diastolic indices occurred among the deter-

Fig. 7.—Relation shown between "fourth phase" and "fifth phase" diastolic readings in the "one-arm" test of K. and S. on students (solid line) and of B. and R. on hospital patients (dotted line).

minations on students; the average difference was considerably higher in this group, 13.5 mm. Hg as compared with 8.5 mm. Hg in the measurements on hospital patients. In a few instances the two indices were so near together as to be practically inseparable.

COMPARISON WITH OTHER METHODS

A. The Palpatory Method: For systolic blood pressure, the conditions affecting the "two-stethoscope" experiments in this series were practically identical with the conditions in the palpatory systolic

Fig. 8.—Systolic readings. Close correspondence shown between the discrepancies of the palpatory method (solid line) and the auscultatory method in the "two-arm" determinations of the same observers. The cases in which K's readings were higher are to the left, those of S. to the right.

measurements previously reported for the same two observers,² so that the two methods may be directly compared. This comparison is shown in Figure 8, the solid line representing the discrepancies of K. and S. with the auscultatory method and the dotted line the same with the palpatory method. The figure shows that although the auscultatory discrepancies in the region of zero have a slightly higher percentage and never on the extreme sides of the curve quite equal the largest

palpatory discrepancies, still the differences are relatively small and well within the limits of experimental variation. In fact, in view of the tendency illustrated above for observers from time to time to change their habits of interpreting the criteria, these two curves approach coincidence as nearly as could be expected if either of these groups of experiments were repeated. The difference between the average discrepancies (3.54 mm. Hg in the auscultatory and 4.08 mm. Hg in the palpatory) is small in comparison with other variables in series as small as these.

We have not investigated the personal factor in the use of Strassburger's palpatory diastolic criterion, as it seemed hopelessly great.

B. The Oscillatory Method: In another article¹ experiments are being reported concerning the personal factor in the interpretation of the oscillatory criteria. The conditions of those experiments do not permit an exactly parallel comparison with our tests of the auscultatory and palpatory methods; the nearest that can be made is with the "one-arm" auscultatory tests, in which the conditions are favorable to the oscillatory indices in four respects: (1) The personal factor connected with the reading of the manometer is not included in these oscillatory results. Further, in contrast to the conditions of actual practice, the oscillatory readings were made (2) on completed tracings, (3) without the need for haste, and (4) without the necessity of dividing the attention between them and the manometer.

The two subjects whose descriptions of the oscillatory systolic criterion seem most alike are "A" and "D." In seventy systolic readings which escaped criticism or expression of doubt by either of them their differences range from zero to 20 mm. Hg and average 2.91 mm. Hg, which, it will be remembered is about twice the average discrepancy in either of the two series of "one-stethoscope" experiments. In view of the conditions, previously mentioned, it is to be presumed that this average would be materially increased in actual practice by these observers, and the comparative showing made by them is decidedly unfavorable to the sudden increase in amplitude or "principle of von Recklinghausen," which they followed. That the ordinary palpatory index of systolic pressure would stand with the auscultatory criterion in the same favorable comparative light if it could be subjected to the "one-arm" test may be assumed from the close correspondence which we found to exist between it and the auscultatory method in the "two-arm" experiments.

The "change in form," the other systolic oscillatory criterion proposed by Erlanger,⁵ is not included in these comparisons, because the

5. Erlanger, Joseph: *Am. Jour. Physiol.*, 1908, xxi, 24.

evidence concerning the personal factor in its use was not considered conclusive. Also Erlanger's method of "intermittent escapement"⁶ for systolic and diastolic determinations was not the subject of experiment.

In the second part of the article on the oscillatory indices referred to above the average discrepancy in a series of diastolic comparisons is 5.4 mm. Hg, which, it will be remembered, is approximately two or three times as great as the average for either fourth or fifth phase determinations in both of our groups of "one-arm" experiments (fourth phase discrepancies of K. and S. averaged 2.6 mm. Hg, of B. and R. 2.47; fifth phase discrepancies of K. and S. 2, of B. and R. 1.76). We have taken our worst showing, the "fourth phase" readings of K. and S. for comparison with these oscillatory diastolic discrepancies; the dotted line in Figure 9 represents the oscillatory results, the

Fig. 9.—Diastolic readings. "Fourth phase" auscultatory discrepancies in K's and S's "one-arm" experiments (solid line) compared with discrepancies in rereading by the same observer ("C") diastolic points in graphic oscillatory records (dotted line). K's higher readings are to the left. The cases in which C's later readings were higher than his earlier ones are charted to the left. The dotted line does not appear to the right, as earlier readings were never higher than the later ones.

solid line the auscultatory. In judging this comparison it must be borne in mind that the oscillatory readings were performed under the four conditions of unnatural advantage mentioned above, that is, conditions which are not enjoyed in practice. Moreover, in this instance, the oscillatory method was favored in another and specially important item in that the marks of but one individual ("C") instead of two were compared—an advantage which is possible only to graphic records, and which was obtained by submitting for marking a second series of photographic prints of tracings identical with a series which had been marked by the same observer eleven months previously.

Figure 9 also shows a pronounced change of habit in interpreting the oscillatory diastolic criterion on the part of "C," his higher readings without exception being found on the second set of tracings.

6. Erlanger, Joseph: Rep. Johns Hopkins Hosp., 1904, xii, 53.

DISCUSSION AND CONCLUSIONS

These investigations are practically limited in scope to a single source of error in blood pressure measurements, namely, personal differences between observers in the identification of auscultatory systolic and diastolic criteria and in reading the mercury manometer. In the "two-arm" experiments, however, anatomic causes of discrepancies or actual differences in blood pressure between the two arms of the subjects could not be ruled out.

So far as our experiments go, there is little to choose in point of definiteness between the common palpatory systolic index and the newer auscultatory criterion. Our findings, therefore, while not including tests of a sufficient number of observers to be conclusive, do not substantiate the impression widely existing at present that the stethoscope offers a much more definite and reliable systolic blood pressure index than that formerly used. While it is not within the scope of this paper to consider at length the relative merits of methods, it may be pointed out that an intelligent choice between the auscultatory and palpatory methods for systolic readings will involve consideration of the following points: (a) the convenience of the palpatory method; (b) its freedom from interference by extraneous noises; (c) the fact that most of the blood pressure data in clinical literature refer to the palpatory method; (d) the fact that in certain subjects the auscultatory readings cannot be made, and that in certain others they are lower than can be obtained by palpation; (e) the fact that, whereas the auscultatory readings are commonly higher than the palpatory, the latter themselves have been found to be somewhat too high in the few instances in which they have been controlled in human subjects by direct manometric measurements.⁷

The commonly used oscillatory indices, according to our analyses, invite much greater vagaries in interpretation than either the palpatory or auscultatory method for systolic readings or the auscultatory for diastolic readings.⁸ This finding, if it receives confirmation, will be particularly important in view of the wide acceptance of the

7. Müller and Blauel: *Deutsch. Arch. f. klin. Med.*, 1907, xci, 517; Volhard: *Verhandl. d. Cong. f. inn. Med.*, 1909, xxvi, 200; Dehon, Dubois and Heitz: *Compt. rend. Soc. de biol.*, 1912, lxxii, 789.

8. Part of the discrepancies in the use of the oscillatory method were attributable to individual differences in the understanding of the criteria to be followed. This factor, we believe, has not appreciably influenced our results with the palpatory and auscultatory methods. The palpatory systolic criterion used by some, however, is the "fully developed" radial pulse wave rather than the first one to be felt. An index which depends on the relative amplitude of pulse waves is obviously much less definite than the appearance of a wave where none before existed; and for this reason as well as because it is the more commonly used criterion, we have accepted the first wave to be felt, although certain theoretic considerations favor the fully developed waves.

oscillatory method as the most "objective," hence the freest from personal factor errors, and its use on this account as a standard or means of "checking up" other methods. Reasons have been presented¹ for the special condemnation of methods in which the attempt is made to use the oscillatory indices with instruments which do not supply graphic records.

Notwithstanding their favorable comparison with the oscillatory method, both of the auscultatory diastolic criteria which have been proposed leave much of definiteness to be desired. This is shown in our "fourth phase" determination by the large number of readings which were rejected because the sound changes were not considered abrupt enough to afford clear readings, as well as by the comparatively large number of higher discrepancies in the comparisons which were made.

Our greatest differences in simultaneous readings occurred in the "fifth phase" experiments, in which, in one instance, we differed by as much as 38 mm. Hg. Particularly in our "two-arm" experiments the number of instances in which we agreed was small. These results we believe would have been modified decidedly for the better if all our subjects had been of the ordinary hospital class. For, in examining the students, who as a rule are more or less excited by the novelty of the medical examination, we have been impressed with the unusually gradual and protracted waning of the artery sounds before their final disappearance. In accord with this impression is our finding of a considerably greater average difference between the fourth and fifth phase readings in the student measurements than in those made on hospital patients. Our experiments on the students indicate better agreement among the fourth phase determinations than in the fifth phase; in the experiments on hospital patients, however, the fifth phase determinations showed a slightly smaller average discrepancy.

In conclusion it should be stated that the differences between blood pressure readings in these experiments would be somewhat lessened if as a basis for comparison the highest reading by each observer on a case or the average of several readings were used instead of individual readings. Better results might also be obtained by combining methods, using one as a check against another. The comparison of single simultaneous readings, however, while it makes for ourselves a somewhat poorer showing than we may hope exists in our actual practice, is the direct way to determine disagreements of observers, and it is obviously the best way to compare results obtained by different methods.