Psychological Bulletin
1966, Vol. 66, No. 6, 481-484

CORRECTING PSYCHOPHYSIOLOGICAL MEASURES FOR INDIVIDUAL DIFFERENCES IN RANGE[1]

D. T. LYKKEN, R. ROSE[2], B. LUTHER[3], AND M. MALEY

Psychiatry Department, University of Minnesota Medical School

Most psychophysiological output variables display marked individual differences in the maximum and often in the minimum levels of which S is capable. Since such variations in range are generally unrelated to the underlying variable of interest, measures of tonic level or of changes in level should be corrected so as to remove their influence. Formulas for this correction are provided together with experimental evidence showing that such range-corrections may accomplish marked reductions in error variance.

Many dependent variables in psychological research display marked interindividual variability in range, that is, individual differences in the maximum level of output of which the subject is capable. Psychophysiological variables commonly show intersubject differences in minimum levels as well. A typical finding is illustrated in Figure 1 for the variable palmar skin potential (SP). Other things being equal, the negative outward potential across the palmar skin varies over time as a function of excitement or arousal. For the 20 subjects represented in Figure 1, minimum SPs were estimated by values recorded during a period of relaxation, and maximum SPs by the highest values produced while the subject was blowing up a balloon to bursting. The vertical bars in Figure 1 show the ranges over which each subject's SP varied between these extremes. Unless one is willing to believe that, for example, Subject 1, when relaxed, is still far more "aroused" than Subject 3 under stress, one must conclude that the limits within which SP varies for a given individual are determined by structural and physiological factors probably unrelated to the underlying variable of interest, arousal. We have observed similar individual differences in range for such variables as skin conductance, heart rate, and skin temperature in studies of more than a dozen different samples, including normals and psychiatric patients. The phenomenon is perhaps characteristic of, but not limited to, psychophysiological output levels. In psychophysical research, for example, sensory thresholds may vary with fatigue, motivation, and the like, but always with idiosyncratic limits; in attitude research, subjects vary greatly in their

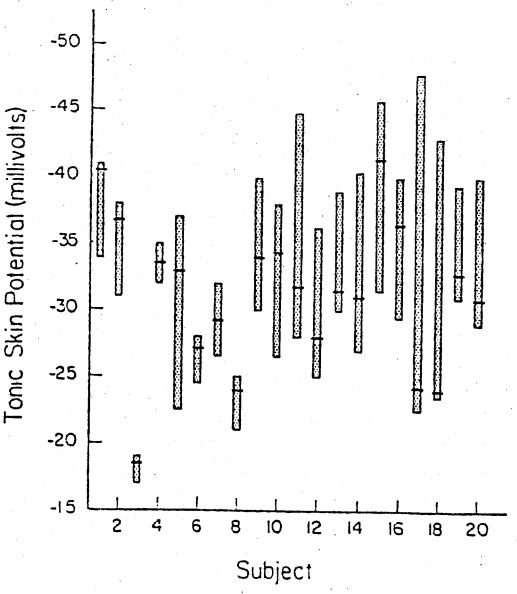

FIG. 1. Individual differences in range of variation of palmar skin potential for 20 subjects. (Horizontal lines indicate potential at the time of measurement of the two-flash threshold, TFT. Subjects are arranged in order of increasing TFT, from 47 milliseconds for Subject 1 to 73 milliseconds for Subject 20.)

[1] Supported by grants from the Graduate School of the University of Minnesota and from the National Institute of Mental Health. We are grateful to the psychiatry departments of the Hennepin County General Hospital and the Minneapolis Veterans Administration Hospital for providing subjects and facilities.

[2] Now with the department of psychology, University of Illinois.

[3] Now with the department of psychology, Queen's University, Kingston, Ontario, Canada.

use of extreme categories of rating scales quite independently of their "true" agreement toward the item being rated, and so on.

During the experiment represented in Figure 1, psychophysical methods were used to estimate each subject's two-flash threshold (TFT), the minimum time interval between two brief flashes of light for which the subject can still see two rather than a single flash. The TFT is lowered by reticular stimulation (Lindsley, 1958, 1961) and by dextroamphetamine (Luther, 1965), and raised by depressant drugs (Rose, 1964). The TFT is lower in normals who score high on the Lykken Anxiety Scale and in anxious psychiatric patients, and has been shown to vary inversely with the sedation threshold (Rose, 1964). Thus, the TFT seems to be related inversely to arousal or cortical activation, and one expects to find a negative correlation between the TFT and SP. The horizontal bars in Figure 1 represent the average value of SP observed for each subject during the measurement of the TFT. The subjects are arranged in the figure in order of increasing TFT (decreasing arousal), with Subject 1 having the lowest TFT (47 milliseconds) while Subject 20 had the largest (73 milliseconds). It is clear that the relation between the raw SP values and the TFT is negligible; their correlation is in fact only −.01. Note, however, that the subjects having low TFTs, on the left in Figure 1, show SP values near the top of their respective ranges, while those with high TFTs, on the right in the figure, show SP values near the bottom of their ranges. If we compute for each subject an index which represents his SP relative to his own estimated limits of SP variation, then the correlation between this corrected value and the TFT rises sharply to −.64. The index used for this correction, first described by Rose (1964), is:

$$\Phi_\rho = \frac{\rho_{ix} - \rho_{i(\min)}}{\rho_{i(\max)} - \rho_{i(\min)}} \qquad [1]$$

where ρ_{ix} is the raw value of the output variable obtained from Subject i in Situation X, while $\rho_{i(\max)}$ and $\rho_{i(\min)}$ are, respectively, estimates of that subject's maximum and minimum output levels. These extreme values may be estimated either by simply monitoring the subject over a sufficient time or else by manipulating that underlying variable for which Φ_ρ is to serve as an indicant.

Some correlational evidence of the utility of this correction method is summarized in Table 1. In 11 separate samples totaling 236 individuals, we have obtained simultaneous measures of the TFT and skin conductance (SC) and, in two of these samples, measures of SP as well; all three variables are putative indicants of some dimension of excitement, activation, or arousal and should therefore intercorrelate. As shown in the table, the

TABLE 1

IMPROVEMENT IN THE CORRELATION BETWEEN THREE INDICANTS OF AROUSAL RESULTING FROM THE CORRECTION FOR INDIVIDUAL DIFFERENCES IN RANGE

Sample	N	Correlations using: Raw values (TFT vs. SC)	"Corrected" values (TFT vs. Φ_{sc})
Normal males	22	−.54	−.76
Normals, both sexes	36	−.41	−.53
Male patients	20	−.61	−.70
Female patients	20	−.50	−.72
Normals, both sexes	15	−.48	−.66
Surgical patients	18	−.47	−.59
Surgical patients	21	−.26	−.80
Psychiatric patients	24	−.45	−.69
Psychiatric patients	20	−.23	−.76
Psychiatric, no drugs[a]	20	−.14	−.54
Psychiatric, on drugs[a]	20	−.49	−.60
Average (RMS) correlation		−.44	−.67
Mean shared variance		19%	45%
Sample	**N**	**(TFT vs. SP)**	**(TFT vs. Φ_{sp})**
Psychiatric, no drugs[a]	20	−.01	−.64
Psychiatric, on drugs[a]	20	−.15	−.59
Mean shared variance		2%	38%
Sample	**N**	**(SC vs. SP)**	**(Φ_{sc} vs. Φ_{sp})**
Psychiatric, no drugs[a]	20	.10	.86
Psychiatric, on drugs[a]	20	.04	.65
Mean shared variance		1%	58%

Note.—Abbreviated: TFT = two-flash threshold, SC = skin conductance, SP = skin potential.

[a] These are two samples of psychiatric patients, one on maintenance dosage of tranquilizers, on whom TFT, SC, and SP were jointly measured.

average correlation between TFT and SC over the 11 samples is −.44. This value rises to −.67 when the range-corrected index Φ_{sc} is substituted for the raw SC values, representing an increase of from 19% to 45% of variance-in-common. In two samples, the mean variance shared by the TFT and SP was only 2% as compared to 38% for the TFT versus Φ_{sp}. In the same two samples, SP and SC correlated only .07 (1% common variance), while range-correcting both variables increased this average (RMS) correlation to .76 (58% common variance). Appropriately, correcting only one of these two variables produces an intermediate correlation averaging .39 in this example.

The increased precision given by the range correction shows itself not only through the increase in correlations between related variables, but also through its effect of increasing the power of significance tests: for example, groups which "should" differ with respect to some psychophysiological variable will show a larger relative mean difference when that variable is range-corrected. This effect is illustrated for skin conductance (SC) in the following two experiments. In the first comparison, 15 subjects' SCs during a standard task were measured after ingestion of 5 milligrams dextroamphetamine sulphate on 3 days and after ingestion of a placebo on 3 randomly interspersed days. Here each subject is his own control, and the correction must compensate only for within-subject range variations from day to day. The stimulant's effect of increasing the raw SC values was itself significant ($t = 3.31$, $p < .01$), and substituting range-corrected units merely increased the t value ($t = 3.95$, $p < .002$). In the second comparison, 20 psychiatric patients receiving maintenance levels of assorted tranquilizers were contrasted with 20 different patients not on drugs. Here the range correction must compensate for between-subject range variations, and its effect on the power of the test of group mean difference is correspondingly greater. The drug group's mean SC was only slightly and insignificantly depressed ($t = .80$), whereas the mean of this group's range-corrected SC scores was very significantly lower than that for the nondrug group ($t = 3.67$, $p < .001$).

We have been dealing here with what may be called *tonic* values of the output variable, for example, average level of the subject's SC under the experimental conditions. Psychophysiologists commonly work with *phasic* fluctuations of the output variable, changes in the tonic level produced by some brief stimulus or other change in the experimental conditions. Thus, a stimulus or change in conditions may produce a transitory increase in SC known as the galvanic skin response (GSR). Such phasic or change scores of course are also subject to the noisy influence of individual differences in range of output variable, when computed in the usual way as the difference between prestimulus and poststimulus values of that variable. This error variance can be removed by computing instead the difference between the corresponding range-corrected values, or by means of the formula:

$$\Delta\Phi = \frac{\Delta\rho_{ij}}{\rho_{i(\max)} - \rho_{i(\min)}}. \qquad [2]$$

Thus, if Subject i shows a tonic conductance of SC_0 which rises to SC_1 after some stimulus j, then his change in conductance or $GSR_{ij} = SC_1 - SC_0$. This raw GSR value may be range-corrected by appropriate substitution into Equation 2 above, resulting in $\Delta\Phi_{ij} = GSR_{ij}/[SC_{i(\max)} - SC_{i(\min)}]$.

It should be emphasized that range-correction of phasic fluctuations or change scores is not by itself the ultimate solution to the problem of selecting the proper units for such variables, unless Φ is linearly related to the underlying variable of interest, ψ, over at least most of its range. For example, if Φ is a growth function of ψ, $\Phi = 1 - e^{\alpha\psi}$, as may be true for the relation of SC to arousal, then the change score, $\Delta\Phi = \Phi_1 - \Phi_0$, will vary as a growth function of the change in Φ times the compliment of Φ_0:

$$\Delta\Phi = \Phi_1 - \Phi_0 = (1 - \Phi_0)[1 - e^{-\alpha(\Delta\psi)}]. \qquad [3]$$

In such cases, the change score *must* be negatively correlated with the prestimulus level, Φ_0, so that, for example, equal change scores obtained at different initial levels will not reflect equal changes in the underlying variable of interest. This is an illustration of the so-

called "law of initial values" (Wilder, 1962). Note, however, that the existence of correlation between a change score and the initial value does not in itself imply nonlinearity in the relation of Φ to ψ nor the need for some further change in the unit of measurement. It is to be expected that the change, produced by a stimulus, in the underlying variable itself may sometimes be related to the initial value of that variable, a relationship which should be reflected in the indicant even with an ideal choice of units.

REFERENCES

LINDSLEY, D. B. The recticular activating system in perceptual discrimination. In H. H. Jasper, L. Proctor, R. Knighton, W. Noshay, & R. Costello (Eds.), *Reticular formation of the brain.* Boston: Little, Brown & Co., 1958. Pp. 513–534.

LINDSLEY, D. B. The reticular activating system in perceptual integration. In D. E. Sheer (Ed.), *Electrical stimulation of the brain.* Austin: University of Texas Press, 1961. Pp. 331–349.

LUTHER, B. R. A comparative study of some arousal-related measures in surgical and psychiatric patients. Unpublished doctoral dissertation, University of Minnesota. 1965.

ROSE, R. J. Preliminary study of three indicants of arousal: Measurement, inter-relationships and clinical correlates. Unpublished doctoral dissertation, University of Minnesota, 1964.

WILDER, J. Basimetric approach (law of initial value) to biological rhythms. *Annals of the New York Academy of Science,* 1962, 98, 1211–1228.

(Received March 1, 1966)