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DAVID F. LOHMAN

SPEARMAN, CHARLES EDWARD (1863–1945) Arguably the most distinguished figure in the history of British psychology, Charles Spearman, although he died in 1945, is one of the notably few psychologists of his period whose pioneering contributions remain widely known in the late twentieth century and are still frequently cited by modern psychologists. Indeed, it would be hard to exaggerate his significance for contemporary psychology. His theories spawned some of the controversies still holding center stage in differential psychology, and his major works, after almost three-quarters of a century, are still a wellspring of problems for contemporary researchers.

Spearman was the first systematic psychometrician and the father of what is known today as classical test theory. He also wrote the first book to deal with a subject matter now recognized as cognitive psychology, thereby crediting him also as a pioneer in that field.

Spearman has perhaps become best known for his methodological contributions, particularly FACTOR ANALYSIS, a widely used mathematical method for analyzing the correlational structure among a number of different variables. On that point of history, however, his claim to priority as the inventor of factor analysis is a bit complicated and calls for a more detailed explication, to be given later on in this article. There seems to be no question, though, that Spearman was the first really important theorist in the study of human mental ability and that he discovered *g*, the general factor in the correlations among all complex mental tests.

Born in London, Spearman also died in London, committing suicide at age 82. Although Spearman's reserved and modest autobiography (1930) is totally silent about his family background and personal life, according to his most famous student, Raymond B. CATTELL (1968), Spearman came from "an English family of established status and some eminence" (p. 110). It is also on record that he was educated entirely in the most upper-class English schools. As a boy he was unusually questioning and reflective; he confesses that in his teens he felt "an excessive but secret devotion to philosophy." He also evinced an aptitude for mathematics and science, and in college he studied engineering. He never sought a career in that field, however, as philosophy remained his chief interest. Having become engrossed in the philosophy of India and desiring to go there to study, he decided he might best accomplish this purpose by joining the British military service, which had stations in India. He imagined that a military career would allow more leisure and freedom for pursuit of his self-directed scholarly interests than any other remunerative occupation, so he applied and received commission in the Royal Engineers of the British Army. Instead of being sent to India, however, he was sent to Burma. There he won a medal for distinguished service in the Burmese War of 1886. He rapidly attained the rank of major, but as his study and interest gradually turned from philosophy to psychology, he began longing for a full-time career in that field. He believed that philosophy could be advanced only through the development of psychology as a natural science, and he was then eager to try his hand at furthering this objective. Later he wrote that joining the army was the mistake of his life, and that "for these wasted years I have since mourned as bitterly as ever Tiberius did for his lost legions" (1930, p. 300). Thus he was a latecomer to a career in psychology. At age 34, he resigned his commission as an army engineer and went to Leipzig University to study psychology under Wilhelm Wundt, who was the founder of experimental psychology and the pioneer of a new scientific psychology as a distinct discipline in its own right, separate from philosophy. After two years' work in Wundt's laboratory, Spearman's studies were interrupted by his call to army service during the Boer War (1899–1902), after which, then newly married, he returned to Leipzig. In 1906 he finally submitted his doctoral thesis ("Normal Illusions in Spatial Perception") to Wundt and received the doctor of philosophy degree in psychology. Spearman always regarded Wundt with great admiration and personal affection and declared that Wundt and Francis GALTON (whom Spearman knew only through reading) were the most important influences in his life. He remained in Germany for one more year to study with the noted experimental psychologists Oswald Kulpe at Wurzburg and Georg E. Muller at Göttingen.

Returning to England in 1907 at age 43, Spearman was hired as reader in experimental psychology in University College, London, in the department headed by the famous British psychologist William McDougal, who soon was impressed by Spearman's originality and productivity as a researcher. Hence, in 1911, when McDougal was offered a chair at Oxford, he recommended Spearman as his successor at University College, and Spearman was appointed Grote Professor of Mind and Logic, a position that was renamed professor of psychology in 1928. He held this position, with a leave for service on the general staff of the British army during World War I (1914–1917), until his retirement in 1932, when he was succeeded by Cyril BURT. During this most productive period of his career, Spearman received many honors in England and abroad, including election as a fellow of the Royal Society and, in the United States, membership in the National Academy of Sciences.

PSYCHOMETRIC THEORY, FACTOR ANALYSIS, AND THE DISCOVERY OF g

Early in his studies in Leipzig, Spearman decided that his aim as a researcher would be, in his words, "to connect the psychics of the laboratory with those of real life (Spearman, 1930)." While still a student in Wundt's lab, Spearman published in 1904 a lengthy and strikingly non-Wundtian article in the *American Journal of Psychology* entitled "'General Intelligence' Objectively Determined and Measured." It became one of the landmarks in the history of psychology. Spearman and his own students further explored and theoretically elaborated its main themes in a great many subsequent articles and books (see also GENERAL INTELLIGENCE).

To begin with, Spearman was attracted to Galton's concept of a *general* mental ability with biological underpinnings as a product of the evolutionary process. The notion of a general ability seemed more compelling to Spearman than the then prevailing doctrine that there are a great number of separate faculties of the mind, such as span of attention, recognition, comprehension, recall, perception, memory, and imagination—the list was virtually unlimited.

Spearman was also attracted by Galton's hypothesis that discrimination and reaction time were fundamentally related to general mental ability and hence could be used to measure it objectively. Spearman knew, however, that the use of these "brass instrument" techniques in Galton's laboratory and especially in later studies (done in 1901) in the same vein by Galton's American disciple James McKeen CATTELL (who coined the term *mental test*) and his student Clark Wissler at Columbia University failed to reveal any substantial correlations among the various Galtonian tests of discrimination and reaction time. This finding flatly contradicted Galton's idea of a general ability that should be reflected in substantial positive correlations among all of the tests. Moreover, these laboratory tests showed no appreciable correlation with the intelligence levels of Columbia College students, which had to be surmised from their course grades, as there were no intelligence tests at that time. These two main findings, issuing from a prestigious psychological laboratory, generally cast a pall over Galton's ideas about the nature and measurement of mental ability. Spearman, however, took an especially critical look at these studies. He himself tested a number of schoolchildren with some of the Galtonian tests and found moderate correlations among the tests and between the tests and teachers' estimates of the pupils' intelligence based on their scholastic performance. This discrepancy between the correlations found in his own study and those found in previous studies demanded an explanation. Spearman's discovery of the explanation led to virtually everything else for which he is now most famous, particularly the invention of factor analysis. Up until this point, the concept of attenuation of correlations had not been recognized. The obtained correlations between any real variables are always based on fallible measures, and the errors of measurement cause attenuation (i.e., underestimation) of the magnitude of the true correlation between the variables. We see here the fundamental formulation of classical test theory, namely, that an obtained measurement, X, is analyzable into two additive components, a true score (t) and random error (e), hence $X = t + e$. It follows that the total variance of X consists of the true-score variance plus the error variance. The e of a given variable, being random, therefore cannot be correlated with the random e of another variable. Only the t components of the two variables can possibly be correlated. Spearman realized that, in evaluating the obtained correlation between variables, one must take into account the proportion of the total variance of each variable that consists of true-score variance. This proportion became known as the reliability coefficient.

Working with this formulation, Spearman invented the correction for attenuation of a correlation coefficient, which yields an estimate of the correlation between the true-score components of the correlated variables. If the obtained correlation between variables x and y is r_{xy}, it is corrected for attenuation by dividing it by the geometric mean of the reliability coefficients of x and y, that is,

$$r_{xy}/(r_{xx}\ r_{yy})^{\frac{1}{2}}.$$

It is also a fact that when there is a restriction of the range of talent in the sample of persons on whom measurements were obtained, compared with the range of talent in the general population, both the reliability and the true-score correlations between variables are diminished accordingly. The correlations obtained in Wissler's sample of Columbia College students, for example, were drastically diminished by the exceedingly low reliability coefficients of the intercorrelated measurements and by the severe restriction of the range of mental ability in the sample. When Spearman corrected the correlations for these attenuating effects, he found such substantial positive correlations among all of the variables as to lead him to suspect that Galton's notion of general ability was really correct after all. After correction for attenuation, not only were the sensory and reaction time tests themselves substantially intercorrelated, but they were substantially correlated with independent estimates of the subjects' levels of intelligence.

Spearman still needed a mathematically rigorous method for testing the hypothesis that a single general factor accounted for all of the correlations among the diverse mental tests. The method he invented was actually just an extension of his formula for the correction for attenuation. By means of this extended formula, he was able to show the correlation between a given test and whatever it had in common with two or more other tests. He termed this common source of variance the general factor and labeled it *g*. For example, if we know the correlations among three variables, *x, y,* and *z,* the correlation of, say, *x* with the general factor, *g,* common to the three variables is

$$r_{xg} = [(r_{xy}\, r_{xz}/r_{yz}]^{\frac{1}{2}}.$$

Similarly,

$$r_{yg} = [(r_{xy}\, r_{yz})/r_{xz}]^{\frac{1}{2}}.$$

Spearman generalized the applicability of this simple formula to the intercorrelations among any number of variables, thus:

$$r_{ag} = [(r_{ab}\, r_{ac} + r_{ab}\, r_{ad} + \ldots + r_{ax}\, r_{ay})/(r_{bc} + r_{bd} + \ldots + r_{xy})]^{\frac{1}{2}}.$$

The correlation of a variable with a factor, for example, r_{xg}, is called a factor loading. If only one factor, *g,* accounts for the correlations among all of the variables, then the correlation between any pair of variables, say *x* and *y,* can be expressed as the product of their factor loadings, that is, $r_{xy} = r_{xg}\, r_{yg}$.

But how could Spearman definitely prove that *g* is the only common factor underlying the correlations among all of the tests? Spearman invented the needed proof, which involves three features of the correlation matrix, the first two of which are inevitable if the third is met within the limits of sampling error: (1) showing all positive correlation coefficients among the tests; (2) showing that the square matrix of correlations among the tests can be arranged in a hierarchical order; and (3) showing that all the tetrad differences are zero. In a hierarchical matrix the correlation coefficients can be ordered from larger to smaller in both directions, from left to right and top to bottom of the square matrix. For example, the following is a perfectly hierarchical matrix of correlations among four different tests, labeled A to D:

Test	*A*	*B*	*C*	*D*
A	—	.56	.48	.40
B	.56	—	.42	.35
C	.48	.42	—	.30
D	.40	.35	.30	—

A tetrad is any set of four correlations in the hierarchical matrix between which two equal-length crossing diagonals can be drawn. In the above matrix, for example, there are only three possible distinct tetrads, that is,

$$\begin{matrix} .48 & .40 \\ .42 & .35 \end{matrix} \qquad \begin{matrix} .56 & .40 \\ .42 & .30 \end{matrix} \qquad \begin{matrix} .56 & .48 \\ .35 & .30 \end{matrix}$$

The number of distinct tetrads (N_T) in a matrix increases rapidly as the number of variables (n) increases:

$$N_T = {}_4C_n = 3n!/4!(n - 4)! \text{ [Recall that } 0! = 1.]$$

Spearman's famous tetrad difference criterion is the difference between the products of each of the cross-diagonal correlations, that is, for the first tetrad in our example, $(.48 \times .35) - (.42 \times .40) = 0$. If all of the possible tetrad differences are 0 (as in this example), it necessarily follows mathematically that the correlation matrix contains only one factor, and ipso facto, all of the correlations can be regenerated from the loadings of each of the variables on this single factor. Applying Spearman's formula for determining the g factor in each of the tests in the above matrix, we find their g loadings are A = .8, B = .7, C = .6, and D = .5. The correlation between any pair of tests, then, is simply the product of their g loadings, e.g., $r_{AB} = .8 \times .7 = .56$, $r_{AC} = .8 \times .6 = .48$, and so forth.

This all looks extremely neat and simple, but that is because this is an artificial matrix intended for didactic purposes. In reality, the tetrad differences are not all equal to 0 but at best are only distributed symmetrically around 0. This would be expected, however, because of the sampling error in correlations obtained from real data. Spearman worked out a formula for the probable error of the mean tetrad differences that could be calculated quite reliably, as the total number of distinct tetrads even in a relatively small matrix is very large. (With 10 tests there are 630 tetrads.) He obtained the frequency distributions of the tetrad differences for many correlation matrices of diverse mental tests and showed that the distributions, in relation to their probable errors, deviated from 0 no more than would be statistically expected by chance, given the sampling error of the correlations in a given matrix. Hence Spearman argued that all of the correlations between different tests was due to one general factor (g) common to all of the tests. The proportion of g variance in a given test is simply the square of its g loading. The square root of the difference between the test's reliability and its squared g loading Spearman termed the test's specificity, or s. The s^2 of a given test is the proportion of its total variance that is specific to that particular test. A test's s, in other words, is what it does not have in common (besides measurement error) with any other test that was entered into the factor-analyzed correlation matrix. Thus, according to Spearman's original theory, the true score (X_t) on each and every distinct test of cognitive ability represents a composite of a general factor (g) common to all tests and a specific factor (s) that is unique to the particular test, $X_t = g + s$. This formulation is Spearman's famous TWO-FACTOR THEORY.

The two-factor theory, however, was destined to be short-lived. Other investigators soon came up with larger collections of tests whose intercorrelations, even though all positive, could not all be arranged hierarchically and hence could not conform to the so-called vanishing tetrads criterion for a single common factor. Spearman at first argued that certain groups of tests that were responsible for breaking the hierarchy were too similar to one another (e.g., vocabulary, similarities, and verbal analogies) to be regarded as truly distinctive tests, and they therefore had "overlapping" (i.e., intercorrelated) specificities. (Of course, by the definition of specificity, to speak of correlated or "overlapping" specificities is self-contradicting.) To restore the hierarchical matrix, Spearman could either eliminate all but one of the similar tests or combine their scores as if they were a single test. Then his "vanishing tetrads" rule again showed there was only a single factor, g. As argumentation based on evidence mounted against Spearman's overly simple two-factor theory, however, he finally admitted the existence of other factors besides g, factors common to only certain groups of tests that are relatively similar in the type of knowledge or skill they call for—categories of tests such as verbal, spatial, and numerical. These factors that are common to only certain groups of rather similar tests Spearman therefore called group factors. Regardless of whatever groups factors could be found in any correlation matrix, however, the g and s remained ubiquitous in all batteries of cognitive tests.

Spearman's theory of mental ability thus evolved finally to include various group factors in addition to g and s. This concession momentarily posed quite a problem, though, because the method Spearman had invented for extracting the g factor from a correlation matrix would work only on a hierarchical matrix that would meet the vanishing tetrad criterion (within the limits of sampling error). It was powerless, mathematically, for dealing with a matrix containing other factors in addition to g and s. (This point is well explicated by Thurstone, 1947, pp. 279–281.) To apply his method of factor analysis, Spearman was forced to make his matrix hierarchical, either by combining any similar tests that, if treated individually, would create a group factor, or by eliminating any tests that broke the hierarchy. This was a most unsatisfactory state of affairs, and some new method was needed for dealing with multiple-factor matrices. The outcome of this situation has fueled disputes over Spearman's priority as the inventor of factor analysis.

Completely unknown to Spearman at the time, and three years prior to the publication of his classic 1904 paper that first described his two-factor theory based on his relatively simple factor-analytic formulas, the eminent mathematician and statistician Karl Pearson had published an obscure paper entitled "On lines and planes of closest fit to systems of points in space." What he had invented here was, in fact, what we know today as principal components analysis, for which Harold Hotelling, in 1933, provided a practicable computational algorithm. It turned out to be the preferred method that has since been used in many different scientific fields for extracting orthogonal components (i.e., uncorrelated "factors") from a correlation matrix of multiple "factors." The first principal component extracted by the computational procedure is necessarily the largest component, in terms of the proportion of total variance accounted for, and is considered the general factor in the particular matrix. But unlike Spearman's method, the number of orthogonal components that can be extracted from a correlation matrix by the method of principal components is limited only by the number of experimentally independent variables. As early as 1909, however, Cyril BURT had proposed a simplified but inexact method called "simple summation" for approximating the results obtained by Pearson's mathematically exact but much more complex formulation. In 1931 Louis L. THURSTONE put forth the same approximate formulation as Burt's, naming it the "centroid" method, which was used extensively by Thurstone and by many other researchers in the empirical development of the multiple-factor theory of mental ability. The upshot is that these methods, as well as principal components analysis and the various modern forms of factor analysis (see Harman, 1976), completely superseded Spearman's much more limited method. All of the modern methods of factor analysis are essentially mathematical derivatives and variations, not of Spearman's formulation of 1904, but of Pearson's formulation of 1901. Spearman's formulation is merely a special case of Pearson's more general formulation. Hence there is some ambiguity regarding Spearman's priority as the inventor of factor analysis, especially if we consider only the methods of exploratory factor analysis in use in the late twentieth century. There is no argument, however, that Spearman was the first to introduce the essential idea of factor analysis to the study of ability, and later to personality. Also, Spearman's momentous discovery of g in all cognitive tests that involve any kind of information processing has been firmly established by innumerable studies in the half-century since he died. Spearman's conception of the nature of g, however, is another story and involves his noegenetic laws of cognition.

Before getting to that, however, mention should be made of two other quantitative methods invented by Spearman that are well known to modern psychometricians and statisticians: (1) the Spearman-Brown prophecy formula, which shows the mathematical relation between the length (e.g., number of items) of a test and the test's reliability coefficient, and (2) the Spearman rank-order correlation coefficient, r_s, which is the most widely used nonparametric alternative to r, the parametric Pearsonian correlation. These formulations can be found in most textbooks of psychological measurement and of statistics.

NOEGENETIC LAWS OF COGNITION AND THE NATURE OF INTELLIGENCE

Spearman's judgment that future historians of psychology would consider his noegenetic laws his most important contribution seems to have been wrong. These "laws" have been largely forgotten compared to his other main achievements.

In Spearman's (1923) theory of mental ability, the g factor is most clearly manifested in tests to the extent that successful performance represents an example of noegenesis. By noegenesis Spearman means the generation, or creation, of new relationships, concepts, or mental content, as contrasted with conditioning, rote learning, and memory, or the reproduction (rather than production) of mental contents. Noegenesis, he held, involves three self-evident processes of cognition, which he termed the noegenetic laws (or principles). The three qualitative principles are as follows: (1) *The apprehension of experience:* "Any lived experience tends to evoke immediately a knowing of its characters and experiencer." (Spearman points out that "immediately" in this context has no temporal connotation but only means the absence of any mediating process.) (2) *The eduction of relations:* "The mentally presenting of any two or more characters (simple or complex) tends to evoke immediately a knowing of relation between them." (3) *The eduction of correlates:* "The presenting of any character together with any relation tends to evoke immediately a knowing of the correlative character." The best tests of *g* should be those that best elicit the eduction of relations and *correlates,* or, in other words, that involve some form of inductive or deductive reasoning.

In addition to these qualitative principles, there are five quantitative principles, which determine individual differences in the manifestations of the three qualitative principles: (1) *Mental energy,* which is the basis of individual differences in *g.* This "energy" (or "power"), whatever its physiological basis (about which Spearman remained agnostic), serves in common the whole cortex or even the whole nervous system. Group factors and specificity reflect the action of particular groups of neurons (analogized as "engines") that partake of the common supply of "neural energy." Any mental task therefore reflects both the potential "energy" and the efficiency of the particular "engine" involved in the performance of the given task. The existence of individual differences in "potential energy" and in the efficiency of specific "engines" is reflected in the factor structure of a battery of diverse mental tests as consisting of a general factor, two or more group factors, and as many specific factors as the number of tests in the battery. (2) *Retentivity:* "The occurrence of any cognitive event produces a tendency for it to occur afterwards." (3) *Fatigue:* "The occurrence of any cognitive event produces a tendency opposed to its occurring afterwards." (4) *Conative control:* "The intensity of cognition can be controlled by conation" (i.e., drive, motivation, will). (5) *Primordial potencies:* "Every manifestation of the preceding four quantitative principles is superposed upon, as its ultimate basis, certain primordial but variable individual potencies." It should be emphasized that a book-length discussion (Spearman, 1923) of these principles reveals them to be much more profound intellectually than is suggested by this very brief summary.

Regarded today as perhaps the most important principle enunciated by Spearman, but not included with his noegenetic laws because it is a strictly psychometric principle, is the principle of *the indifference of the indicator.* This refers to the fact that variation in the particular form or content of the items that enter into a test of intelligence is totally irrelevant so long as there is a large number and a wide diversity of items, provided all of them are to some extent *g* loaded. In other words, the total scores derived from *any* sizable collection of diverse test items that to some degree involve the noegenetic principles will all measure one and the same *g.* Hence an almost unlimited variety of so-called intelligence tests will all rank individuals in much the same order. (Spearman rather reluctantly and tentatively equated *g* with "intelligence," a word he seldom used, and even then he usually put it in quotes.) However, Spearman noted one crucial proviso for the validity of his principle of the indifference of the indicator of *g,* namely, that for a test item to be appropriate, its fundaments must be readily familiar to the subjects being tested. He defined fundaments simply as the things between which relations are to be educed. (E.g., *table* and *chair* are fundaments; an educed relation is *furniture.*) Analogy problems exemplify the eduction of relations and correlates, for example, "boy:man::girl:________.

In Spearman's greatest work, *The Abilities of Man* (1927), he makes clear the important distinction between objectively identifying *g,* which he had accomplished, and explaining the nature, or cause of *g,* which he had not accomplished. He wrote,

> That which this magnitude [*g*] measures has not been defined by declaring what it is like, but only by pointing out where it can be found. It consists in just that constituent—whatever it may be—which is common to all the abilities inter-connected by the tetrad equation. This way of indicating what *g* means is just as definite as when one indicates a card by staking on the back of it without looking at its face. Such a defining of *g* by site rather than by nature is just what was meant originally when its determination was said to be only "objective." [1927, pp. 75–76]

Spearman's factor analysis of more than 100 extremely diverse kinds of tests (Spearman & Jones, 1950) confirmed his conclusion that the "site" of the largest *g* loadings is in those tests that most completely involve the eduction of relations and correlates and that also have the quality of "abstractness," that is, tests of abstract reasoning. All kinds of diverse tests, however, showed positive, albeit often modest, *g* loadings, such as pitch discrimination, perceptual speed, and reaction time. Spearman's conclusions in this regard have been amply confirmed by modern research (Jensen, 1987). Although Spearman proposed a number of hypotheses concerning the possible physiological basis of *g*, he did no empirical research on that aspect of the problem. He hoped, however, that the nature of *g* would eventually be explained in terms of brain physiology—an eventuality, he wrote, "whereby physiology will achieve the greatest of all its triumphs" (1927, p. 407).

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ARTHUR R. JENSEN

SPEEDINESS A relationship between intelligence and mental quickness is reflected in our culture and language. Early theories about the structure of intelligence by Edward THORNDIKE and by Louis THURSTONE included speed as an independent dimension, and most abilities tests reward faster performance. Speed in a wide variety of performances is positively related to a wide variety of cognitive abilities, to age changes, and to physiological correlates (Birren, Woods, & Williams, 1980). Two perspectives have emerged about how mental speed relates to intelligence. *Speediness* has been identified as a common factor in test performance and defined as quickness in undemanding or overlearned tasks (Horn, 1968). Conceptualized by John Horn and Raymond Cattell as more cognitive than sensory, speediness is separable from the major intellectual dimensions responsible for perception, reasoning, problem solving, and memory. A different view is that speed of information processing is fundamental to intelligence (Eysenck, 1967). This approach focuses on correlations between "chronometric" procedures like reaction time and intelligence quotient (IQ). Mike Anderson (1992) has extended Hans EYSENCK's position, integrating GENERAL INTELLIGENCE and specific abilities within a speed of processing mechanism, to distinguish these from noncognitive modules—and thereby arguing that speed provides a sufficient explanation for intelligence.

PSYCHOMETRIC SPEEDINESS

Horn and Cattell have defined speediness as a second-order factor, reliant on but broader than primary perceptual speed. Also termed "general cognitive speed" (Cattell, 1971) or "general perceptual speed" (Hakstian & Cattell, 1978), speediness is identified within the Horn-Cattell theory as *Gs*. At least before old age, it is relatively independent from fluid intelligence (*Gf*) and crystallized intelligence (*Gc*) and from