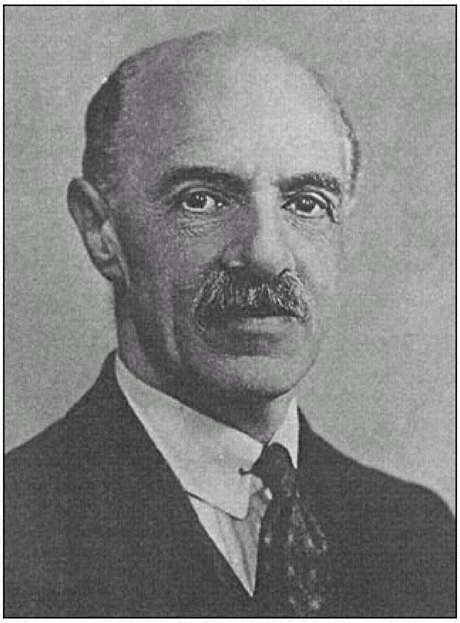

Photo of Charles E. Spearman
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# Chapter 6— Charles E. Spearman: The Discoverer of *g*

Arthur R. Jensen

A person who wants to become a psychologist but, for whatever reason, must begin study for a degree later than most PhD candidates can take heart from the career of Charles Edward Spearman (1863–1945). Spearman began his formal study of psychology when he was 34 years old and did not complete his PhD until 10 years later. As this chapter will attest, one reason for his delayed entry into the field seems to be inherent in the history of Spearman's intellectual development. Another was the happenstance of war, which interrupted his graduate study. His late start seems in no way to have hindered his brilliant career, however. He went on to become the most influential figure in British psychology in the 20th century and was one of the great originators in psychology, especially in the fields of differential psychology (the study of individual differences) and psychometrics (the measurement of mental traits). The history of these specialties could not be written without recognition of Spearman's creative achievements. After Sir Francis Galton (chap. 1, *Pioneers I*) founded these fields in the second half of the 19th century, Spearman, in the first half of the 20th was their chief engineer, architect, and developer.

Spearman once described his career as "one long fight" (1930a, p. 330). Although he held one of the most prestigious professorships in Britain and earned many honors, including election as fellow of the Royal Society and membership in America's National Academy of Sciences, his contributions were by no means universally esteemed. In particular, many experimental psychologists were antagonistic toward Spearman's legacy. A few years after Spearman's death, Zangwill, the professor of psychology at Cambridge University, historically Britain's bastion of classical experimental psychology, wrote a popular textbook in which he made the following prophecy on the future acceptance of Spearman's major contribution:

> We may submit, with due humility, that factorial analysis, despite its impressive mathematical procedures will strike the future historian of psychology as a brilliant but misguided departure from the central path of empirical psychology. The Spearman factors will take their not unworthy place in the limbo of the discarded elements of the mind. (1951, p. 205)

It is clear today that Zangwill's dismal forecast has been massively contradicted, if the *Science Citation Index* (SCI) and the *Social Science Citation Index* (SSCI) over the 50 years since Spearman's death are indicators of the scientific impact and scholarly interest in his work. Typically, the citation rate of even very prominent psychologists drops to near-zero within the first decade after their death. After that, the cumulative count of their citations shows a marked negative acceleration. Then it levels off, with virtually zero increments in subsequent years. The trend for Spearman is just the opposite. For the 50 years following his death, the curve recording his cumulative citations listed in the SCI and SSCI for every five-year interval is positively accelerated, as shown in Figure 6.1. This is an exceptional phenomenon. Except for E. L. Thorndike (chap. 10, *Pioneers I*), Spearman's notable contemporaries are virtually never cited in the present-day literature except in publications dealing with the history of psychology.

These citations show that most of this continuing interest involves Spearman' s discovery and theory of the *general factor* in all mental abilities, which he called the *g* factor. Although his strictly statistical contributions are still valuable, they are now so well-known that they are usually used without attribution. His specific method of doing factor analysis has long been defunct; it is not described in detail in modern textbooks. Neither of these could have added much to the frequency of his present-day citations.

Spearman's career also serves to validate a bit of academic folk wisdom that I have encountered on committees selecting someone for a faculty position from a pool of applicants for an assistant professorship, most of whom are new PhDs. One bit of evidence that usually weighs heavily in these evaluations is the notion that a new PhD who has published at least one research paper in a peer-reviewed journal is more promising than a candidate who published nothing as a graduate student. I doubt that the validity of this hunch has ever been formally tested, but Spearman was a positive example.

Two of Spearman's most frequently cited articles (Spearman, 1904a, 1904b) were published in the prestigious *American Journal of Psychology* in 1904, three years before he received his PhD. And both are still being cited in the current literature nearly a century after their publication. They are generally recognized as exceptionally original and important contributions. The second article, "Gen-

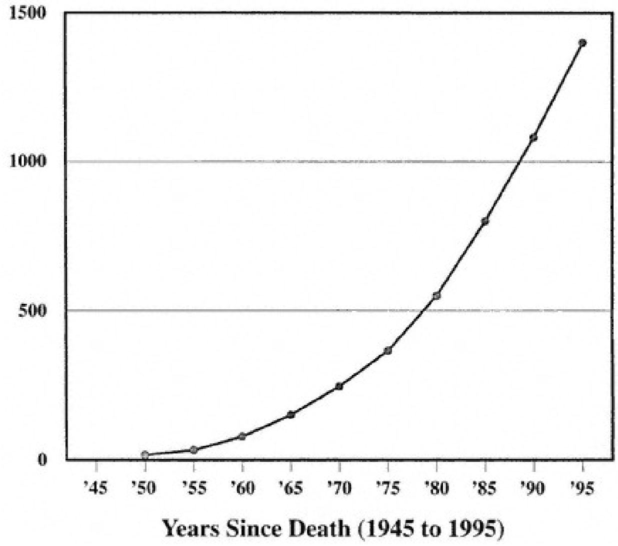


FIG. 6.1.
Cumulative record of Spearman's citations in the SCI and SSCI in five-year intervals over 50 years, from the date of his death (1945) to 1995.

eral Intelligence, Objectively Determined and Measured," is a classic in the history of differential psychology and psychometrics. Moreover, this was not a doctoral thesis done under a mentor's supervision. It was not remotely related to his PhD thesis, and was even antithetical to the interests and sympathies of his mentor, Wilhelm Wundt (chap. 3, *Pioneers III*), the founder of the first laboratory of experimental psychology. Despite Spearman's late beginning in psychology, his self-initiated research as a graduate student not only auspiciously presaged his later eminence but was even the main feature of it.

**Biography**

My study of Spearman has led me to believe it would be virtually impossible for anyone to write a full-scale personal and professional biography of the man. As for his personality, nearly all we have to go on is a short and overly modest autobiography, which Carl Murchison (chap. 11, *Pioneers II*), the editor of *A History of Psychology in Autobiography* (1930a), persuaded him to contribute to the first volume in that series. It is obvious that Spearman was an exceedingly private person. He abhorred revealing himself in any personal way. He was reticent regarding even his purely intellectual side, as he made clear in his autobiography, stating, "One's own history, even on its intellectual side, involves much that is very intimate. To publish this abroad seems not only egoistic but even of dubious propriety" (Spearman, 1930a, p. 299). Among the many autobiographies I have read, Spearman's anchors one extreme on the scale going from personal self-concealment to self-revelation; the autobiography of another famous British psychologist, Havelock Ellis (1859–1939), anchors the opposite extreme. Although both were great men, such is the difference between a mathematically minded factor analyst and a literary minded sexologist.

Spearman's last doctoral student was the eminent psychologist Raymond B. Cattell (1905–1998), who described Spearman as possessing "remarkable charm and a capacity to stimulate and reassure [students]" (Cattell, 1978, p. 1038). Besides Cattell, the only psychologists I have met who had any personal acquaintance with Spearman were Cyril Burt, Hans Eysenck (chap. 20, this volume), and Philip E. Vernon. Their answers to my questions about Spearman the man were all variations on the theme that he was a reserved and rather austere yet kindly man of high ethical, moral, and intellectual integrity, who seldom hesitated to express his own views strongly and was forthrightly critical of whatever he disagreed with. He was also described as unstintingly helpful to his students and colleagues.

The main reason for the obscurity of Spearman's professional life is that he died just a few months after the end of World War II, when England was in such turmoil that no one took up the task of writing his biography. Because he died at 82, only a few of the relatives, who might have contributed knowledge of the man, outlasted him. And all of the professional contemporaries who knew Spearman personally are now deceased. Some of his correspondence with other psychologists, particularly with Burt, Spearman's successor as professor at University College, London, survives (see Lovie & Lovie, 1993), but it deals only with highly technical aspects of factor analysis.

### ***From Philosophy to Psychology***

Born in London on September 10, 1863, Spearman's background has been described as that of "an English family of established status and some eminence" (Cattell, 1978, p. 1038). As a boy he showed strong academic ability and interests. By age 10 he was already concerned with philosophical issues. About his early schooling he wrote that there was "nothing worth chronicling except a secret devotion to philosophy. . . . My deepest urge was to probe further into the nature of existence, knowledge, and goodness" (1930a, p. 299). His strong subject in school and college was mathematics, and he considered becoming a mathematician. Conceding to practicality, however, he abandoned this course to prepare for a career with better prospects for employment, and graduated with a degree in civil engineering.

Philosophy still dominated Spearman's interest, however, and in the course of his self-study in that realm, he became fascinated by the philosophies of India. As a graduate engineer without a job and with a burning desire to study Indian philosophy, he joined the British Army's Royal Corps of Engineers, in hope that he might be stationed in India. Instead of India, however, he was sent to Burma to take part in a military campaign in the Burmese Wars. There his work as an army engineer won him a medal for distinguished service and promotion to the rank of major.

Eventually Spearman's studies led him to dissatisfaction with philosophy because, unlike the empirical sciences, he could find no means to prove its theories. He wondered if the study of psychology might lead him to the solution of this problem. Spearman began reading the psychological literature, speculative and empirically limited though it was, in the early 1890s. His study revealed that the only laboratory of experimental psychology and the only professor of psychology—in fact, the only university in the world that granted a doctoral degree in psychology—were in Leipzig, Germany, where the leading light was Wundt, now considered the father of experimental psychology. So Major Spearman, then 34, resigned his commission in the army and took off for Leipzig to study psychology under Wundt. Concerning his 14 years of army service, Spearman later wrote that "it was the greatest mistake of my life . . . [based on] the youthful delusion that life is long. . . . For these almost wasted years, I have since mourned as bitterly as ever Tiberius did for his lost legions" (1930a, p. 300).

Unfortunately, Spearman was not yet completely free of his army career. His study in Leipzig was interrupted by the outbreak of the Boer War in South Africa (1900–1902). He was recalled to military duty for two years as a staff officer. After completing his service in the war, Spearman returned to Leipzig to resume his study under Wundt. He also visited many other universities and became acquainted with the leading German psychologists of that time—Külpe, Müller (chap. 5, this volume), Husserl, Stumpf (chap. 4, this volume), and Stern (chap. 6, *Pioneers II*). Wundt, however, was the major German influence on Spearman's career. In his autobiography he acknowledged his feeling of gratitude for Wundt's personal kindness toward him, saying that it became "one of the dominant sentiments" of his life.

### *From Wundt to Galton*

An intellectually more important influence during Spearman's student years was another illustrious figure whom he never knew personally, the English polymath

Sir Francis Galton. Because Wundt and Galton were the two major influences in Spearman's career, it may be of interest to compare the characteristics of these two giants in the history of psychological science, as viewed by psychology historian Edwin G. Boring:

> Wundt was erudite where Galton was original; Wundt overcame massive obstacles by the weight of his attack; Galton dispatched a difficulty by a thrust of insight. Wundt was forever armored by his system; Galton had no system. Wundt was methodical; Galton was versatile. Wundt's science was interpenetrated by his philosophy; Galton's science was discursive and unstructured. Wundt was interminably arguing; Galton was forever observing. Wundt had a school, a formal self-conscious school; Galton had friends, influence and effects only. . . . Wundt was personally intolerant and controversial, whereas Galton was tolerant and ready to be convicted of error. (Boring, 1950, pp. 461–462)

It was Galton's book *Inquiries Into Human Faculty and Its Development* (1883), the first important work on differential psychology, that first attracted Spearman. In this book Galton described an odd assortment of "brass instrument" devices and techniques for measuring sensory, motor, and mental capacities. He also introduced the idea of behavioral genetics, suggesting the use of identical and fraternal twins for estimating the relative contributions of heredity and environment to behavioral traits. He offered anecdotal evidence on the remarkable behavioral similarity between identical twins as examples of the influence of heredity. But Spearman was even more intrigued by an idea in Galton's most famous work, *Hereditary Genius* (1869). Galton believed that persons differ widely in a general trait that can be characterized as innate cognitive ability. Besides this *general* ability Galton also recognized a number of *special* abilities or talents, such as linguistic, mathematical, musical, artistic, and memorial. It was the notion of general cognitive ability that especially captured Spearman's interest, however, as well as the idea of measuring individual differences in this general ability with simple tests of sensory discrimination and reaction times to visual and auditory stimuli.

The influences of Wundt, the founder of experimental and nomothetic psychology, and of Galton, the originator of differential psychology and psychometrics, are blended in Spearman's own career. This is evident in his formulation of general laws of cognition and in his empirical analysis of human mental abilities into a general ability that enters into every kind of cognitive activity and special abilities peculiar to various cognitive skills as manifested in different tests, tasks, or talents.

Although it is evident in Spearman's writings that he was as much a hereditarian as Galton was, he himself had no research interest in the genetics of individual differences. He did no original research on it, but he did write one expository article on heredity and ability (1914–1915) and took a cursory glance at the subject in his major work, *The Abilities of Man* (1927). Although Spearman was a Fellow of The Eugenics Society (founded by Galton in 1904, later renamed The Galton Institute), he expressed more hard-boiled opinions on eugenics than Galton ever did, writing, "One can conceive the establishment of a minimum index [of *g*, or general intelligence] to qualify for parliamentary vote, and above all, for the right to have offspring" (Hart & Spearman, 1912, p. 79). In 1912, this bold statement probably did not violate the operating standards of political correctness as it would today.

**Predoctoral Research Activity and the Beginnings of Factor Analysis**

As a predoctoral student, Spearman's most important research activity was wholly unrelated to his mentor's interest or even to his own doctoral dissertation on optical illusions. Quite aside from his doctoral work, and completely on his own initiative, Spearman investigated the Galtonian notion of a general intellectual ability common to all cognitive tasks. He performed two little experiments, based on groups of 24 and 22 pupils in a "village school" and in a boys' "preparatory school." No psychology student today would be allowed to base even a master's thesis on such small samples and such unimpressive data: teachers' rankings of the pupils on "school cleverness," "common sense," "native intelligence," and standings on examinations in several school subjects. (A halo effect in such data could have spuriously inflated nearly all of the positive correlations among the teachers' ratings and class grades.)

But Spearman's data as such were of little importance. What proved to be momentous were his original ideas and the mathematical formulations for which the data merely served as a vehicle (Spearman, 1904a, 1904b). Spearman evidently had to do all the heavy calculations by hand or perhaps he paid a student to do them for him. In any case, some of the extensive computational work was faulty, though in trivial ways. The errors were later discovered, because Spearman published all of his raw data, which have been re-analyzed by modern computers (Fancher, 1985). Such numerical imperfections have also been pointed out in the works of Galileo, Newton, and Mendel, of course, without diminishing the import of their scientific contributions. A British statistician writing on the origin of factor analysis aptly commented on Spearman's pioneer effort:

> Factor analysis is a highly sophisticated multivariate statistical method which was born before its time. In 1904 the older strands of descriptive statistics and probability had only just begun to coalesce to form modern mathematical statistics. The Biometric Laboratory at University College, London, under Karl Pearson was only just under way and Fisher and all his works lay 20 years in the future. The ideas of correlation developed by Pearson and Yule were virtually the only tools to hand and even they were not widely known and used. What is remarkable is not that Spearman's first attempts were so crude but rather that he was able to give ex-

pression to such a deep and potentially fruitful idea at all. (Bartholomew, 1995, p. 216)

### *Classical Test Theory*

What Spearman accomplished in his two 1904 papers was to lay the foundation for classical test theory and to invent a method later to be known as *factor analysis*, by means of which he achieved the first empirical test of Galton's theory of general mental ability, or *g*. But the broader and more fundamental innovation was that this work opened the door conceptually to what we now know as *latent trait theory.* Spearman provided the first demonstration of the idea that the relationships (correlations) among a number of *manifest* or observed variables could be explained by some smaller number of unobservable *latent* variables, of which the manifest variables are a function. Spearman's *g* factor was the first objectively determined and measured *latent variable* in the history of psychology.

What Spearman showed in 1904 with his meager data was that the matrix of correlations among all the diverse measures in his study could be "explained" by a single factor, *g*. All of the correlations between the different tests were positive, suggesting that they all measure something in common. By means of the mathematical algorithm he invented, Spearman was able to determine, with some margin of error, the degree to which each of the observed measures was saturated (or loaded) with the source of variance common to all of the other measures in his analysis. In other words, he invented a method for determining the correlation of each of the manifest variables with the single latent factor, *g*. The important empirical finding was that, in accord with Galton's original conjecture, all of the measures, including the tests of sensory discrimination, had *g* loadings, although some of them were more highly *g*-loaded than others. Spearman gave the name *specificity* to the non-*g* part of each variable, the variance that it does not have in common with any of the other variables in the analysis and thus is unique to it.

This formulation that every mental test measures a *general factor* (*g*) and a *specific factor* (*s*) became known as the *two-factor theory.* Because Spearman did not precisely reveal the thought processes that led to this formulation, a number of highly detailed and quite technical articles have tried to explain exactly what Spearman did during this most creative period while he was still a mere graduate student and how he did it (Bartholomew, 1995; Burt, 1949; Fancher, 1985; Lovie & Lovie, 1993; Thomson, 1947).

The two-factor theory was not very long lived, however. Within a decade following Spearman's original formulation other psychologists, most notably Cyril Burt, obtained data on much larger samples with a greater number of mental tests, and found evidence for other factors besides *g*. Also, Spearman's particular method of factor analysis was not suited to analyzing a correlation matrix with multiple factors. His method was really conceived as what today is called a *con-*

*firmatory factor analysis*, intended to test only one specific hypothesis—in Spearman's case, his two-factor theory. Hence the method was too limited to serve as an *exploratory factor analysis* in which, with no initial hypothesis about the number and nature of the factors required to "explain" all the correlations, the investigator analyzes a correlation matrix to estimate these values. Therefore, more complex methods, devised by the mathematical statisticians Karl Pearson and H. Hotelling (principal components), and the computationally simpler adaptations of principal components by Burt (simple summation) and L. L. Thurstone (chap. 6, *Pioneers III*) (multiple-factor analysis) became the preferred methods for analyzing correlation matrices that could not be adequately modeled in terms of a single common factor, as in Spearman's analyses.

Besides the general factor common to all tests of mental ability, these multiple factor methods also revealed factors that are common only to certain groups of tests; hence they were termed *group factors*. Group factors emerge clearly only when data from three or more tests of three or more abilities (e.g., verbal, numerical, and spatial)—hence at least nine tests—enter into the analysis. Spearman's two-factor theory ($g + s$) holds up only when each of the tests in the analysis is clearly distinct from all of the others. Such tests can have only $g$ in common. Spearman reluctantly and even grudgingly acknowledged the existence of group factors, but never conceded them much importance. They detracted from the nice simplicity and singular dominance of $g$ in terms of the proportion of variance in a battery of tests accounted for by $g$. But the demonstration of multiple factors in no way eliminated the ubiquitous $g$ factor, which is present in virtually every imaginable kind of mental ability test. No one has yet succeeded in creating any mental ability test that is without some loading on $g$, whatever else the test might measure.

Spearman's early formulation (1904a, 1904b) was instigated by a consequential study performed in James McKeen Cattell's psychological laboratory at Columbia University. Cattell (1860–1944) obtained his PhD under Wundt a few years before Spearman and then spent some time with Galton in London. Like Spearman, Cattell was less influenced by Wundt than by Galton. In 1901, Cattell and his student Clark Wissler tested Galton's theory of general ability and the idea that sensory discrimination and reaction time are correlated with such commonsense indicators of mental ability as scholastic performance. Their research participants were 325 students in Columbia College and the measures of intelligence were average grades in classics and mathematics. Also a number of Galton's tests of sensory discrimination and reaction time were administered. The correlations among the scores on Galton's tests and between these scores and class grades were pathetically small. This led to the conclusion that Galton was wrong on two counts: (1) there is no general factor in diverse mental abilities and (2) simple sensory tests do not measure "intelligence" as this word is commonly understood. So prestigious and influential was the reputation of Cattell and Columbia's psychological laboratory that this study cast a pall over Galtonian thinking in psychometrics for more than a half a century—an indictment that was aided and abetted by the practical success of the intelligence test invented by Alfred Binet (chap. 5, *Pioneers III*).

In hindsight it seems incredible that the faults of the Cattell–Wissler study were not obvious to everyone. But there still was no psychometric science in 1902, and psychometric naiveté prevailed. The idea that measurement error and restriction of the "range-of-talent" can drastically reduce the size of the correlation coefficient and hence underestimate the true correlation in the general population seems not to have occurred to any psychologist before Spearman. Recall that Karl Pearson invented his correlation coefficient ($r$) only in 1896, and it was scarcely used in psychology before the development of psychometric theory, initiated by Spearman and soon developed further by others, mainly Burt, Thomson, Thorndike, and Thurstone. Examining the Cattell–Wissler study, Spearman put his finger on its chief fault—measurement error probably constituted a large proportion of the total variance in test scores. That is, the manifest variables were exceedingly weak indexes of the latent trait $g$. Galton's studies, too, had been vitiated by measurement error. But at that time no one knew precisely how to quantify measurement error. That, too, was one of Spearman's contributions.

To make a historically long and complicated story short and simple, Spearman conceived mental test theory in terms of the simple formulation $X = t + e$, where X is an observed measurement, such as a test score, $t$ is a hypothetical *true score* (a latent variable), and $e$ is a random error of measurement. From this simple model many important psychometric formulations were derived. The total variance $V_X$ of a distribution of test scores or measurements of any kind is composed of the *variance* of $t$ plus the variance of $e$—that is, $V_X = V_t + V_e$. From this, the *reliability* ($r_{XX}$) of the test can be defined as $r_{XX} = V_t/(V_t + V_e)$. The traditional measure of $r_{XX}$ is the Pearson correlation between scores on the same test given on two different occasions or the correlation between equivalent forms of the test. From this, Spearman deduced the means for correcting an obtained correlation ($r_{XY}$) between the scores on two different tests, X and Y, yielding the correlation between the true scores on each test. This procedure is termed *correction for attenuation.* The corrected (or *disattenuated*) correlation ($cr_{XY}$) is $cr_{XY} = r_{XY}/(r_{XX})(r_{YY})$. Many other statistical and psychometric formulations followed. Although Spearman had no formal training in statistics, for his time he was a remarkably able statistician.

**Academic Career**

In 1907, after Spearman received his PhD in Leipzig, he returned to London, where he succeeded the noted psychologist William McDougall as reader in the Department of Experimental Psychology at University College, London, an unusually distinguished position for a beginner. Later he was promoted to Grote professor of Mind and Logic and then professor (and head) of Psychology. More important than the titles of his posts, as Thomson (1947) pointed out in his superb obituary of Spearman for the Royal Society, was that from the beginning of his tenure until long after his retirement in 1931, Spearman founded and built up "a new school of psychology, with a new outlook, the experimental and statistical. . . ." (p. 373). Rooted essentially in the Darwinian and Galtonian tradition emphasizing a biological view of human nature and armed by Spearman with methods developed in psychometrics, statistics, and experimental psychology, this approach to behavioral science later became known as the London School. Its best-known exponents were Cyril Burt, Hans J. Eysenck, and Raymond B. Cattell (no relation to J. McK. Cattell). Nowadays the essential viewpoint and methodology of the London School has been largely assimilated in the fields of psychometrics, behavioral genetics, and cognitive neuroscience. Spearman devoted the rest of his life to examining his theory of mental ability, particularly the *g* factor and its relationship to educational and social variables, and made interesting discoveries along the way. The main thrust of his work is summarized in his two most frequently cited books, *The Nature of "Intelligence" and the Principles of Cognition* (1923) and *The Abilities of Man* (1927). (For a review of these books, see Carroll, 1991.) In *Creative Mind* (1930b) Spearman explained creativity in terms of his principles of cognition. After his retirement in 1931, he wrote a large two-volume work on the history of psychology, *Psychology Down the Ages* (1937), a fascinating but peculiarly skewed history that devotes much space to demolishing "faculty psychology" and most prominently features Spearman's own theoretical views and contributions. It was his final major effort to extricate psychology from speculative philosophy and move it into the domain of natural science. His last book, published posthumously in collaboration with Wynn-Jones, summarizes and updates his theory and empirical research on *g* and the few group factors that had been established at that time (Spearman & Jones, 1950).

Shortly after his retirement in 1931, Spearman went to the United States as a consultant on a large factor analytic study of abilities conducted by his former student Karl J. Holzinger, then a professor at the University of Chicago. This work, which promoted what came to be known as the Spearman–Holzinger Unitary Trait Study (1933–36), has figured prominently in most textbooks on factor analysis. The presence of several group factors was inescapable, but all together they accounted for less of the total variance in all the tests than did the *g* factor alone—a finding that has since been confirmed in factor analyses of countless other test batteries (Carroll, 1993).

In his 83rd year, on September 17, 1945, as a patient in the University of London Hospital, in poor health and suffering the infirmities of old age, Spearman dramatically ended his life by leaping from a top-story window of the hospital. I once asked Raymond Cattell, a former student and friend of Spearman's, if he had any specific explanation for Spearman's action. He did not and could only surmise, knowing Spearman, that it was probably a rational decision.

**Major Theoretical Contributions**

Spearman never regarded himself as a methodologist. He invented his methodological and statistical contributions only as tools for the investigation of his main substantive interest, the nature of cognition. Of his five books, he always considered his first one, *The Nature of "Intelligence" and the Principles of Cognition* (1923), the most important. On this point, however, history has clearly second-guessed him. *The Abilities of Man: Their Nature and Measurement* (1927) is now generally regarded as his magnum opus. It is by far the most frequently cited. Note that Spearman put "intelligence" in quotation marks in the title of his first book. He continued to do so in nearly all his subsequent writing, in part to distinguish it from *g* but also as an implication of his belief that intelligence is a poorly defined and muddled concept: "'Intelligence' has become a mere vocal sound with so many meanings that finally it has none" (1927, p. 14).

***Principles of Cognition***

Spearman postulated three *noegenetic* "laws" as the fundamental "axioms" of cognition, regarding them as inherent and self-evident properties of the human mind, or the brain. The term *noegenesis* refers to the induction or deduction of new knowledge or mental content, derived from sensory experience acted on by his three noegenetic principles.

The first noegenetic law, the *apprehension of experience*, is the immediate awareness of the attributes of whatever has one's focus of attention. The raw elements of apprehension are *called fundaments*.

The second law is the *eduction of relations*, the tendency for the perception of any two or more fundaments to evoke mentally a relation between them. For example:

*Good* − *Bad* ? *Opposite*

The third law is the *eduction of correlates*, a *fundament* presented together with a *relation* evokes a knowing of its correlated character. For example,

*Good* − *Opposite* ? *Bad*

To these three laws were added five quantitative principles of cognition that affect the quality of noegenesis as manifested in an individual's cognitive activity: *mental energy* (the basis of *g* conceived of as the "eduction of relations and correlates"); *retentivity* (the basis of conditioning, learning, and memory); *fatigue* (a refractory period following a cognitive event that produces a tendency opposing its immediate re-occurrence); *conative control* (the effect of drive or motivation on cognition); and *primordial potencies* (individual differences in each of these quantitative principles).

### *The Nature of* g

Spearman's concept of *g* has endured several decades of misunderstanding and controversy, but now is generally accepted as a central construct in the science of human mental ability (Neisser et al., 1996). Spearman understood the problem of talking about *g* in purely verbal terms when it is actually a nonverbal formulation arrived at by mathematical means and can be strictly defined only in those terms. Yet he also believed that *g* represents something more than just the mathematical algorithms that define it. The *g* factor must have underpinnings that are independent of the test scores and mathematical manipulations that identify it, because *g* is not a necessary consequence of either psychometrics or factor analysis. No general factor has been found, for example, in the domain of personality inventories, which yield only uncorrelated group factors. We can note which mental tests reflect *g* more (or less) than other tests, but this tells us little or nothing, because tests of highly dissimilar appearance can have the same *g* loadings. Hence their visible characteristics, their content, their difficulty, or even their apparent cognitive complexity afford few if any clues to the essential nature of *g*. Spearman stated the problem:

> Notice must be taken that this general factor, *g*, like all measurements anywhere, is primarily not any concrete thing but only a value or magnitude. Further, that which this magnitude 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 abilities interconnected by the tetrad equation [i.e., the central mathematical formulation in Spearman's demonstration of *g*]. 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 is meant originally when its determination was said to be only "objective." Eventually, we may or may not find reason to conclude that *g* measures something than can appropriately be called "intelligence." Such a conclusion, however, would still never be a definition of *g*, but only a "statement about" it. (1927, pp. 75–76)

Spearman's "theorem" of the *indifference of the indicator* means that *g* is reflected in any and all tests that involve any degree of "eduction" (i.e., inductive or deductive reasoning) regardless of their form or content, provided the *fundaments* composing the test items are familiar to those who take the test. A corollary of this "theorem" is that when a number of different test batteries, each composed of a large number of diverse cognitive tests, are factor analyzed, they should all yield approximately the same *g* factor. This has been borne out empirically (reviewed in Jensen, 1998, pp. 86–87). Spearman discovered that all tests are more highly *g* loaded in samples drawn from the lower half of the population distribution of IQ than in samples from the upper half of the distribution. In other words, for persons with higher IQs, less of the total variance is attributable to *g* and more is attributed to the various group factors and specificity, as compared with persons with lower IQs. Mental abilities of high-*g* persons are more clearly differentiated than in low-*g* persons. This phenomenon, which Spearman dubbed the *law of diminishing returns*, has been further substantiated in modern studies (reviewed in Jensen, 1998, pp. 585–588). Spearman (1927, pp. 388–391) also discovered the now well-established sex difference in spatial visualization ability, by noticing that spatial tests are much more highly *g* loaded for females than for males. Spatial tests have relatively small *g* loadings for males and have larger loadings on the group factor of spatial ability. Spearman found no evidence of a sex difference in *g* itself, and this, too, has been substantiated in recent analyses. When sex is included as a variable in factor analyses of a variety of mental tests, it shows a near-zero loading on the *g* factor, although sex has significant loadings on certain group factors (Jensen, 1998, pp. 531–543).

Spearman disliked describing *g* in purely verbal terms, but he did state that *g* appears in all mental activities that involve "the eduction of relations and correlates." Also he noted that the property of "abstractness" increases a task's *g* loading. Yet even sensory-motor tasks that hardly seem "cognitive," such as pitch discrimination, weight discrimination, perceptual speed, and choice reaction time, have some *g* loading, although it is much smaller than, for example, verbal and figural analogies, number series, and arithmetic reasoning, which are all highly *g*-loaded.

**g *and the Metaphor of Mental Energy***

The verbal analogy or metaphor that Spearman most often used to "explain" the hypothetical basis of *g* was *mental energy.* At times he also spoke of "power," "force," and "neural energy." The complete metaphor invokes a factory (i.e., a person's brain) with various machines that perform different functions (group factors). All of the machines are driven by their connection with a gear that is powered by a single motor with a constant energy supply (*g*). The energy supplies to different factories (various individuals' brains) have different amounts of "horsepower." Now if we measured the output rates of each of the various machines in a number of different factories, we would find all of the different machines' output rates to be correlated with one another, and a factor analysis of the correlations would reveal a large general factor—call it a "horsepower factor"—that accounts for the differences between the various factories' productivity. But this, of course, would not reveal the actual source of this "horsepower factor"—it could be steam, or gas, or electricity, or nuclear power. To find out, we would have to get inside the factories to inspect their working parts.

Spearman remained theoretically agnostic about the physical basis of this metaphorical "mental energy." He knew that factor analysis, as a purely mathematical technique, could not prove the existence of *g* or explain its nature. Such understanding depends on finding that *g* has significant correlations with physical variables, perhaps in brain physiology. He suggested such physiological causes as the richness of the capillaries supplying blood to the brain and the efficiency of the brain's metabolic processes. Although some physiologists speculated about the brain processes involved in *g*, brain physiology in Spearman's day was too primitive to afford any real help. As Spearman wrote in his autobiography, "The physiologists who had claimed to assist psychology were . . . drawing heavy drafts on the future" (p. 304).

It is also important to show that individual differences in *g* factor scores have predictive validity for real-life outcomes, such as scholastic performance, occupational level, income, and other personally and socially important variables. Spearman's greater interest, however, was the physical basis of *g* rather than its social correlates. He wrote, "The final understanding of *g* must come from the most profound and detailed direct study of the human brain in its purely physical and chemical aspects" (1927, p. 403).

**Present *g* Theory and Research**

During the 30 years between Spearman's death and the middle of the 1970s, *g* theory was in the doldrums, more because it seemed incompatible with the political zeitgeist than for any scientific reason. The transitory debate between Spearman and Thurstone over representing the factor structure of mental abilities in Spearman's fashion, as a unitary general factor (plus specificities for each test), versus Thurstonian fashion, as a number of independent group factors but no general factor, had long since been completely resolved. Thurstone showed that the various group factors could be correlated with one another and that a factor analysis of these factor correlations would yield a higher order factor, which is *g*. Also, a substantial part of the total test variance remains in the group factors after they are residualized from *g*. Hence a hierarchical structure like that in Figure 6.2 can represent within a single model both Spearman's *g* and Thurstone's group factors. (Thurstone called the first-order factors *primary mental abilities*, a term never used by Spearman.) Factor analyses performed on hundreds of psychometric data sets show that such a hierarchical structure, with *g* at the apex, best accounts for the correlations among virtually all of the presently known psychometric variables in the domain of human cognitive abilities (Carroll, 1993).

**Conclusion**

Empirical research on *g* has flourished in recent years. Virtually all of it has been referenced and reviewed in detail elsewhere (Jensen, 1998). Some of the main points that were not demonstrated empirically in Spearman's own work seem

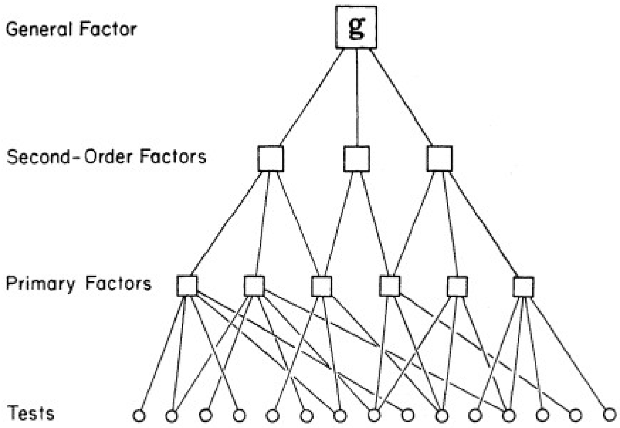


FIG. 6.2.
A three-strata factor hierarchy, showing first- and second-order factors (represented by squares) with *g* (the only third-order factor) at the apex. The factors increase in generality (i.e., the number of tests and lower order factors in which they are loaded) at each higher order in the hierarchy. Among virtually all of the tests of cognitive abilities that have been factor analyzed, there turn out to be about 20 to 30 well-identified primary factors and some 4 to 6 second-order factors. At the third order there appear to be no factors besides *g* (Jensen,1998). Copyright © 1998 by Praeger Publishers. Reproduced with permission of Greenwood Publishing Group, Inc., Westport, CT.

worth indicating, if only briefly. Spearman would probably be happy to know that he had generally presaged many of these recent findings.

• The *g* loadings of a wide variety of psychometric tests that have been subjected to factor analysis represent a perfectly continuous variable ranging between about +.20 and +.80 and show a roughly normal distribution centered around +.50. Hence it is incorrect to think of *g* as reflected by just certain types of mental tests but not by others.

• The general factor in a diverse collection of learning tasks is the same factor as the *g* of psychometric tests.

• The *g* factor cannot be described in terms of the surface features of the tests that reflect it or even in any psychological terms. Highly dissimilar tests can be equally *g* loaded. Strictly speaking, *g* is not really an *ability* at all. It is a cause of individual differences in all cognitive abilities. It is a latent variable that presumably reflects certain properties of the brain elicited by all tests of mental ability, regardless of their form or information content as long as their fundaments are appropriate for the persons tested. However, *g* should not be thought of as necessarily representing the essential design features of the brain, such as neural circuits, cell assemblies, functionally specialized modules, or the specific processes involved in perception, learning, and memory. Rather, *g* reflects individual differences in some property (or properties) of the brain that influences the speed and efficiency of all cognitive operations, thus causing them all to be positively correlated in the population. This property identified as *g* differs widely among individuals.

• Individuals' absolute levels of *g* rapidly increase with age from early childhood to maturity and then gradually decrease in later maturity and old age. Individuals differ in these rates of increase and decline.

• There is no pure test of *g*. Although all cognitive tests have some *g* loading, every test has some specificity (*s*). Most test batteries also measure one or more group factors in addition to *g* and *s.* A very large *g* loading (.70 to. 80) is the *sine qua non* of the total score on all so-called IQ tests, which typically reflect certain group factors, such as verbal, spatial, and numerical.

• The *g* factor is not confined just to mental test scores. It is the chief active ingredient in the practical predictive validity of all test batteries used for selection—in college admissions, assignment of personnel to specialized training schools in the armed forces, and employment. This is because *g* is correlated with individual differences in actual performance in all these domains. The validity of *g* for predicting success in training and performance in various jobs depends on the complexity of the job's cognitive demands. Some types of work are much more *g* demanding than others, and the predictive validity of highly *g*-loaded tests is higher for the more *g*-demanding occupations. Statistically removing the *g* factor from selection tests would so drastically reduce their predictive validity as to render them practically useless. The group factors independent of *g* have relatively weak predictive validity, and then only for certain specialized types of jobs that require particular talents. Even general physical health is more highly related to *g* than to socioeconomic status. It is interesting to note that the *g* loadings of various tests are the best predictor of the degree to which spouses' test scores are correlated with each other. Group factors (independent of *g*) apparently contribute virtually nothing to the correlation.

• Spearman noted that across a wide variety of mental tests there was considerable variation in the magnitude of the average difference between groups of European ancestry and groups of sub-Saharan African ancestry. He conjectured that the size of these average differences for various tests is directly related to the difference in the size of the tests' *g* loadings. That is, the larger a test's *g* loading, the larger is the average White–Black difference. Spearman himself never tested this hypothesis. But his conjecture has since been borne out in more than 20 studies based on large samples and comprising nearly 100 different cognitive tests, including various measures of reaction times. (Details and references in Jensen, 1998, chapter 11; Jensen, in press; also comment by Neisser et al., 1996.) Every data set based on large and representative population samples of Black and White individuals that has been found displays the phenomenon predicted by Spearman, which therefore has the status of empirical fact.

• Spearman supposed that *g* was largely genetically determined and that the group factors were largely environmental. This has been shown by evidence on differences in the heritability of various psychometric tests based on studies of monozygotic (MZ, identical) and dizygotic (DZ, fraternal) twins. (The difference between the correlations for MZ and DZ twins affords an index of *heritability*, defined as the proportion of the total variance in test scores attributable to genetic factors.) It is found that tests' *g* loadings are a better predictor of their heritability coefficients than are any group factors independent of *g*, singly or in combination. Also predicted by a test's *g* loading is another genetic phenomenon known as *inbreeding depression*, or the decrement in the average test score of the offspring of genetically related parents (e.g., cousins) as compared with the average score of the offspring of unrelated parents. The higher a test's *g* loading, the greater is the effect of inbreeding depression in lowering the test scores.

• Spearman's hope that *g* would be found to have physical correlates in the brain has been realized in a number of studies, although most of these findings still need to be replicated to be regarded as firmly established (Jensen, 1993, 1998). Studies show correlations between *g* and a number of physical variables that have no conceptual connection with either psychometrics or factor analysis. Specifically, the magnitude of a test's *g* loading predicts that test's degree of correlation with the following variables: choice and discrimination reaction times; nerve conduction velocity in the brain's visual tract; head size and brain size; the brain's glucose metabolic rate (measured by PET scan); and the amplitude, rate of habituation, and complexity of the wave form of the average evoked potential (i.e., the brain's electrical reaction to an external stimulus, such as the sound of a sharp "click").

Knowing that these physical variables are correlated with *g* does not begin to explain *g*, of course. These findings only indicate that brain variables are in some way related to *g*, and they provide clues for further investigation of its physical basis. Exactly how or why these physical variables are related to *g* is still unknown. Discovering how many other anatomical, physiological, or biochemical brain variables may be involved and deciphering the whole causal chain resulting in *g* is a challenge for brain research. The explanation of *g* in terms of the brain should be a paramount scientific goal of future research. Its eventual accomplishment, given the accelerating pace of brain research, may be witnessed in the near future—in Spearman's hopeful words, "whereby physiology will achieve the greatest of all its triumphs" (1927, p. 407).

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