General Mental Ability: From Psychometrics to Biology

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Abstract

Individual differences on diverse tests of mental abilities that range in complexity from simple reaction time to abstract reasoning are all positively correlated in the population. The total covariance among all such tests can be analyzed into a number of uncorrelated components of variance, or factors, that, in terms of their generality, are hierarchical, with the most general factor, or g, *at the apex. This* g *factor is common to every type of cognitive performance, whatever other ability factors may be involved (e.g., verbal, spatial, numerical, musical, etc.), and is the crucial factor in most tests' practical validity. Its correlations with various tests' heritability, inbreeding depression, heterosis, average evoked potentials, brain metabolism, and many other physical correlates indicate that as a product of evolution it is profoundly enmeshed with many organismic variables. A theory based on empirical evidence links* g *to neural processes involved in the speed and efficiency of information processing.*

A major goal for a theory of human mental abilities is to explain the basis of the empirical fact of *general mental ability* (Jensen, 1987a). I will summarize the empirical findings of my program of research on this subject that seem most important for a theory of general mental ability. They are based on laboratory studies of the relationship between measurements of individual differences in two classes of variables: conventional psychometric tests, on the one hand, and measurements of individual differences in the speed and efficiency of information processes based on techniques of mental chronometry, on the other.

But first, some essential definitions.

Ability refers here to conscious and voluntary acts that meet an objective standard, for example, jumping over a two-foot hurdle, playing a designated note on the piano, naming the capital of Iraq, or solving a chess problem. A person's performance must be repeatable with better-than-chance consistency under similar circumstances to be considered an ability.

Mental, in this context, refers to an ability for which (in the general population) individual differences in sensory acuity or physical strength or dexterity per se contribute negligibly to variance (i.e., individual differences) in attaining the performance standard that defines the ability.

General refers to a well-established phenomenon in psychometrics: In large representative samples of the general population, individual differences in any item of behavior described by the above definition of *mental ability* are correlated only positively with individual differences in every other item of mental ability. A factor analysis of the all-positive matrix of correlation coefficients among a variety of mental abilities (usually measured by diverse psychometric tests) reveals the presence of a *general factor* (that is, the one component of variance that all of the diverse ability variables have in common) and indicates the correlation of each variable with the general factor. (The correlation between a variable and a factor is termed a *factor loading*.) The general factor in a battery of diverse mental ability tests is variously termed Spearman's *g* (after its discoverer), or psychometric *g*, or simply *g*.

Different ability factors (i.e., hypothetical sources of individual differences) are *hierarchical*, in the sense that the factors at each successively higher level of the hierarchy have greater generality than the factors at a lower level. (A factor's generality refers to the number of variables that have substantial loadings on the factor.) The *g* factor stands alone at the apex of the generality hierarchy, as shown in Figure 1. (Examples of other well-established ability factors, at a lower level of generality than *g*, are verbal, numerical, and spatial visualization factors.)

The *g* factor in a hierarchical factor analysis of a number (say, 10 or more) of diverse psychometric tests is quite stable across different samples of the general population, across different collections of tests, and across different models of factor analysis that permit the extraction of a general factor when such a factor exists. The stability and construct validity of the derived *g* increase as a function of subject sample size and the number and diversity of the tests entered into the factor analysis. As these variables increase, the observed *g* asymptotically approaches what might be thought of statistically as the "true" *g*.

Characteristics of *g*

Besides being the most general factor in a collection of diverse mental tests, *g* usually accounts for more of the total variance in the entire battery of tests than any other factor; in typical test batteries it generally accounts for more variance than all of the other significant factors combined.

The *g* factor is by far the chief "active ingredient" in the practical predictive validity of mental tests used in educational and personnel selection and placement in various training programs in the armed forces

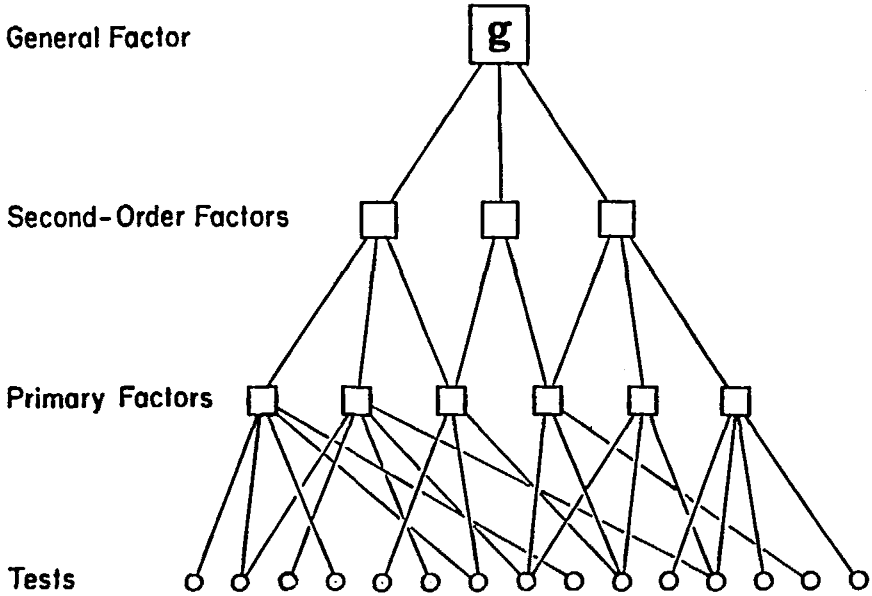

Figure 1: A hierarchical factor structure of mental abilities, with factors increasing in generality at each higher level of the hierarchy.

(Gottfredson, 1986; Jensen, 1988). With the *g* variance statistically removed, the validity of the test scores used for such purposes is typically reduced to almost zero. A very large *g* loading is the sine qua non of all modern IQ tests, whatever other factors may be reflected in the total variance of IQ.

Because *g* is loaded in every variety of mental test, it is so general that it is impossible to describe it in terms of the tests' formal characteristics or in terms of any particular information content or skills required by the specific items. The *g* factor reflects a quality of mental ability stripped of all the specific information content or skill called for by any particular item or class of items. The source of *g* is apparently individual differences in the efficiency of information *processes* (Detterman, 1987; Vernon, 1987). The highly varied knowledge and cognitive skills seen in the items of conventional psychometric tests are merely convenient vehicles for the estimation of *g*.

That *g* is a real phenomenon and not merely an artifact of psychometric tests and the mathematical manipulations of factor analysis is evident from the fact that *g* is correlated with a number of variables entirely outside the realm of psychometrics. Tests' *g* loadings, more than any other factors or visible features of the tests, are related to such variables as (a) the test's spouse correlations, (b) their heritability coefficients as estimated from monozygotic and dizygotic twin correlations, (c) the extent to which test scores are affected by inbreeding depression (and its opposite, heterosis, or "hybrid vigor"), (d) various genetic kinship correlations, (e) certain features of the brain's evoked electrical potentials, (f) the standardized difference between the average test scores of representative samples of blacks and whites, and (g) reaction times (RT) to a variety of elementary cognitive tasks (ECTs) (Jensen, 1983, 1985a, 1987b, 1987c). Also, the IQ and scores on other highly *g* loaded tests are significantly correlated with a number of physical variables; for instance: stature, head size and brain size independent of body size (separately within sexes), and rate of the brain's glucose metabolism, to mention a few (Haier et al., 1988; Jensen & Sinha, in press). IQ also has a probably pleiotropic (genetic) correlation with myopia (Cohn, Cohn, & Jensen, 1988).

Reaction Time in Elementary Cognitive Tasks

In the past decade or so, a great many laboratory studies of individual differences, using chronometric techniques, have established a relationship between the speed of information processing and psychometric *g* (Detterman, 1987; Vernon, 1987). The primary variables have been inspection time (IT) (Kranzler & Jensen, 1989) and RT in a variety of ECTs. The ECTs are designed to be so simple for the persons tested that all of them can easily perform the task correctly. The only reliable source of individual differences is RT, that is, the interval between task presentation and the subject's overt response, which typically consists of lifting the index finger from a push-button. The ECTs are so simple that RTs average less than 1 sec. The ECTs are devised to measure the speed of response in such elementary tasks as the following: stimulus apprehension (i.e., simple RT to the onset of a single stimulus), discrimination and choice RT, visually scanning a series of 1 to 7 digits to determine the presence or absence of a specified "target" digit (Neisser paradigm), short-term memory scanning of a recently memorized set of 1 to 7 digits to determine the presence or absence of a given "target" digit (Sternberg paradigm), semantic verification (i.e., determining whether a stimulus (e.g., **AB**) does or does not verify a previously given statement (e.g., **B after A**), and search of highly over-learned semantic information in long-term memory to determine whether two highly familiar words (e.g., **hot-cold**) are synonyms or antonyms (modified Posner paradigm) (Eysenck, 1987; Jensen, 1982a, 1982b, 1985b, 1987d, 1987e; Jensen, Cohn, & Cohn, 1989; Jensen, Larson, & Paul, 1988).

Error rates are extremely low on all of these RT tasks. All subjects can perform them with 100 percent accuracy under nonspeeded conditions.

Although the RTs average less than 1 sec. on even the most complex of these ECTs, they show highly reliable individual differences. Most significantly, these differences are correlated with IQ and other *g*-loaded test scores, with *r* ranging from about −.1 to −.5 for various ECTs. The multiple correlation based on the RTs from a number of different ECTs (we've tried as many as 11 different ECTs in one study) is considerably higher, of course, than that for any single ECT. But there seems to be a correlation ceiling at about .70. This correlation ceiling is due at least in part to the fact that the RT variance necessarily includes peripheral sensory-motor components, which are not related to individual differences in information processing. Reducing this noncognitive component by subtracting simple RT from the RT to more complex tasks, such as discrimination RT, tends to increase the RT-*g* correlation (Jensen & Reed, 1990).

Our studies have revealed two other variables besides RT that are probably important to consider for a theory of *g*. Although both of these variables are correlated with RT, they also show some correlation with *g* independently of RT.

The first is *intraindividual variability* in RT, that is, the fact that an individual's RTs fluctuate from trial-to-trial; this variability is measured by the standard deviation of the subject's RTs across trials, labeled RTSD. It generally has a larger *negative* correlation with *g* than does the overall median RT; that is, persons who are higher on *g* typically show more consistent RTs throughout the test trials on a given ECT. Individual differences in the consistency of RT are correlated across all ECTs. As a reliable human difference, this phenomenon suggests there is some rapid periodicity or oscillation in neural excitatory potential related to the efficiency of information processing at any given moment.

The second variable might be termed a *processing decrement* associated with increased information load. For example, if subjects are required to perform a *dual task*, such as having to retain in short-term memory a string of several digits to be recalled immediately after they perform a choice RT task, three main effects are observed: (a) the RT is slower than it would be if performed as a single task, that is, without having to retain the digits; (2) recall of the digit string is slower and errors are more likely than would be the case without the intervening RT task; and (c) RT is more highly correlated with *g* in the dual task than in the single task condition, provided the extra cognitive burden imposed by the dual task does not strain information processing to the point of a complete breakdown in performance (Jensen, 1983, 1985a, 1987b, 1987c; Vernon, 1983).

A variety of experimental effects similar to this has led to one of the important theoretical constructs in cognitive psychology, namely, *working memory* (WM), which has been referred to as the "scratch pad" of the mind. WM is the aspect of short-term memory that encodes and manipulates incoming information, rehearses it for storage in long-term memory, and relates it to other information retrieved from long-term memory. It is empirically clear that there are individual differences in the *capacity* of WM. If the load of incoming information or the required manipulations of it exceeds the capacity of the individual's WM, there is a momentary breakdown in information processing that calls for repeated input of the information. Various experimental measurements of individual differences in capacity of WM are substantially correlated with *g*.

The capacity of WM has been theoretically analyzed as the resultant of two fundamental variables that can be conceptualized in neurological terms. The Erlangen School of Psychology (Lehrl & Fischer, 1988), in Germany, hypothesizes the capacity (C) of WM as a product of the *speed* (S) of information processing (in bits per sec.) and the *duration* (D) of the neural traces of information input (in sec.) absent rehearsal. Hence,

$$\text{C bits} = \text{S bits/sec.} \times \text{D sec.}$$

The physiological basis of the speed component of information processing was originally hypothesized by T. E. Reed to be neural conduction velocity (NCV) in the brain (Reed, 1984, 1988).

Processing speed per se is advantageous to information processing because of the limited capacity of WM and the rapid loss of information in the absence of continuous rehearsal to consolidate it in long-term memory. The faster that incoming information can be processed and the less it needs to be rehearsed, the sooner new information can be dealt with and the greater is the amount of information that can be processed per unit of time. Hence, the speed of neural processes in the cerebral cortex and the underlying connective neurons affects the efficiency, thoroughness, and depth of information processing. Therefore we find a correlation between individual differences in speed of information processing (measured in ECTs) and scores on non-speeded, highly *g*-loaded tests of general knowledge and complex reasoning, such as conventional IQ tests and Raven's matrices.

Neural Conduction Velocity (NCV)

A substantial correlation between NCV and scores on a highly *g*-loaded test (Raven's Advanced Progressive Matrices) was found in a recent study (Reed & Jensen, 1989). Short-latency visually evoked potentials (i.e., average wave form records of repeated presentations of the same stimulus) in response to pattern-reversal stimulation and recorded over the primary visual cortex were obtained on 147 male undergraduates. The latencies of the earliest clearly-defined neural impulses transmitted from the retina through the visual tract to the visual cortex are quite short—70 to 100 msec. Dividing an individual's head length by the mean latency of his visual evoked potential (VEP) gives an estimate of NCV. These NCV estimates for potentials averaging about 100 msec (V:P100) showed a significant correlation ($r = +.26$, $p < .002$) with IQ scores on the Raven Matrices. Corrected for restriction of the range of IQ in the college sample raises the correlation to +.37, and correction for attenuation (which was not attempted) would raise the correlation to perhaps as high as +.50. Figure 2 shows the mean IQ within each quintile of the V:P100 measure of NCV. It indicates that the speed of neural transmission in a single, well-defined nerve tract that involves no more than four synapses is correlated with a measure of *g* based on a nonspeeded, self-paced test of complex reasoning.

Our interpretation of this correlation between NCV in the visual tract and *g* is based on the reasonable hypothesis that, since the neurons in the visual tract and in the cortex share a common origin and have common features (e.g., small caliber axons and similar conduction speeds), they are very similar, and hence individual differences in visual tract NCVs and cortical NCVs are correlated. Because information is transmitted from one cortical region to another via axons at some velocity and across synapses with some delay, the mean NCV and cumulative synaptic delay would affect the speed of information processing at every level of cognitive complexity. Individual differences in mean cortical NCV, therefore, would appear to be a basic causal component in *g*.

Neural Oscillation

The intertrial (or intraindividual) variability in RT, which is correlated with *g*, is hypothesized to reflect neural oscillation. We know that individual neurons are periodically excitatory and refractory, and that large numbers of neurons may show synchrony in their oscillation in excitatory potential. This could be the basis for the overt oscillation we see in RT. Neural oscillation acts as "noise" in the nervous system that degrades the efficiency of information processing. A rapid rate of oscillation is more favorable to *g* than a slower rate. This can be explained in terms of a simple analogy. If we think of oscillation as a "neuronal shutter," analogous to the shutter of a camera, then the more rapid and shorter the duration of the "open" and "shut" phases of the shutter, the less will be the moment-to-moment detail that is lost, or shut out, from a continuous input of stimuli and the chaining of operations while processing information in WM.

Summary

Three properties of the brain are hypothesized as a physiological basis of *g*: Individual differences in (a) the *speed of neural conduction* (including synaptic delay), (b) the rate of *oscillation* of excitatory potential

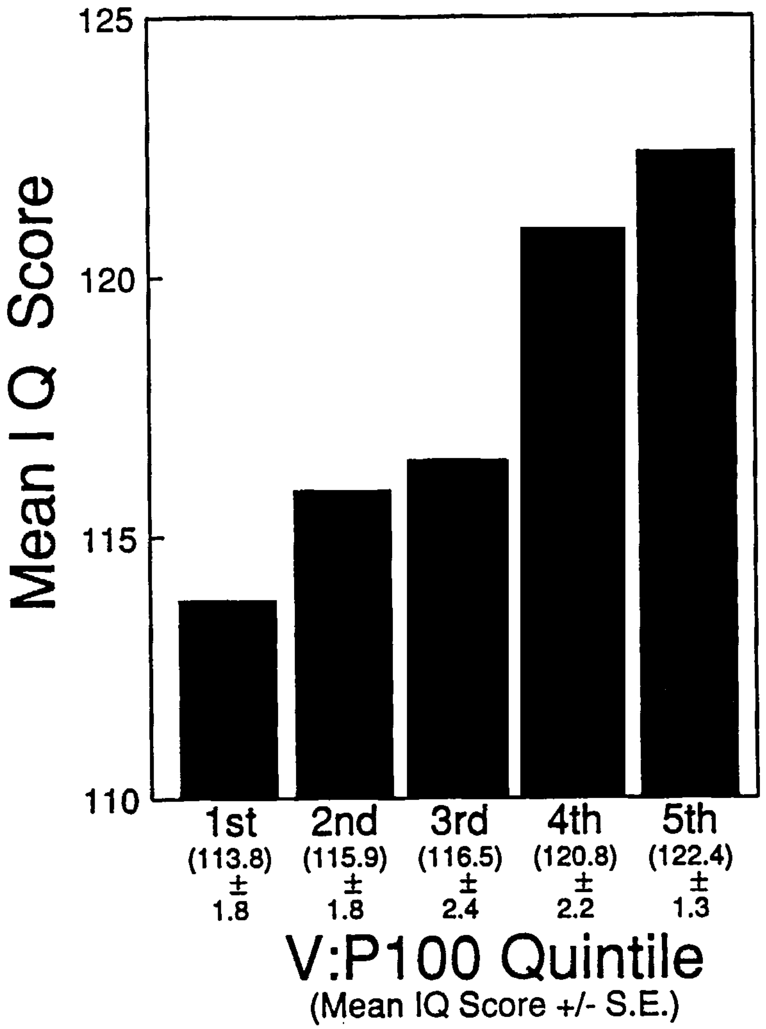

Figure 2: **Distribution of mean IQ scores in V:P100 quintiles (i.e., NCV based on the P100 latency) of 147 male college undergraduates. The distribution of NCV, from the lowest NCV (1.75 m/sec.) to the highest (2.22 m/sec.) was divided into quintiles, each containing 20% of the students. The linear regression of individual IQ on quintile number has a slope of 2.21 IQ points per quintile, with no significant deviation from linearity.**

in individual neurons and groups of neurons acting in phase, and (c) the *duration* (or conversely, rate of decay) of the traces of recently input information in neural assemblies. A higher level of *g* is the result of faster neural conduction, a faster rate of oscillation, and a slower rate of decay of neural traces.

This hypothesis does not deny the obvious necessity of hypothesizing specific neural structures and their complex functional organization or patterning to explain the facts about information processing. But at present we have virtually no knowledge of the extent to which these design features of cortical functioning contribute to individual differences in *g*. We do have evidence now which suggests that brain neural conduction velocity alone may account for some substantial part, perhaps as much as 25%, of the *g* variance in the population. It seems most likely that the design features of the brain are less important in *g* than in the narrower group factors of mental ability and special talents, which reflect also specific learned skills and automatized cognitive algorithms in response to certain classes of problems. Although the proposed theory is put forth tentatively as scaffolding for further theoretical development and empirical discovery, I would maintain that the explanation of *g* must eventuate as one specialized aspect of a theory of the brain—its neurological structure, its physiology, its evolution, its ontogeny, and the genetic basis of variation in its properties.

Finally, I should emphasize that the present formulation is not intended as a theory of individual differences in achievement, or creativity, or success in life. Although *g* undoubtedly plays an important part (Jensen, 1980), these complex outcomes surely involve many other conditions as well—various traits of personality, interests, values, ambition, motivation, opportunity, specialized abilities or talents, training and the automatization of skills through assiduous practice, and self-confidence, to name only a few.

Nevertheless, the substantial correlations of *g* with a host of "real life" variables that people have regarded as important throughout the history of civilization, not only to the individual but to society as a whole, make *g* one of the most significant factors of the human condition. It is most worthy of further scientific study.

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