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The theory of intelligence and its measurement

A.R. Jensen *

Univ. of California, Berkeley and The Institute of Mental Chronometry, 3330 Southlake Drive, Kelseyville CA 95451, United States

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ABSTRACT

Mental chronometry (MC) studies cognitive processes measured by time. It provides an absolute, ratio scale. The limitations of instrumentation and statistical analysis caused the early studies in MC to be eclipsed by the 'paper-and-pencil' psychometric tests started by Binet. However, they use an age-normed, rather than a ratio scale, which severely limits the ability of IQ tests to probe the physical basis of differences in cognition. For this reason, Arthur Jensen reinitiated mental chronometry in the 1970s. He designed an apparatus that measures reaction time to a task known as the Hick paradigm that requires the testee to respond to a display of 1 to 8 lights. Faster decision times were related to psychometric *g*, with theoretically important consequences. He was able to do this, where many other studies had failed, mainly because his apparatus clearly separated movement (MT) from reaction time (RT, also called 'decision time'.) Interestingly, while RT is clearly related to IQ, MT is not. Principal components analysis reveals RT to be a cognitive variable and MT a motor variable. Failure to distinguish between them drastically obscures the correlation between composite RT (i.e., RT + MT) and cognitive variables. When Jensen (2006) reviewed the literature on MC he found there was a shocking lack of standardization in the administration, recording, and analysis. Consequently, the results of a study conducted in one lab, even though measured in absolute time, could not be compared directly against those from another. Termed "method variance," this is a major obstacle to the advancement of MC. For that reason, Jensen's Institute of Mental Chronometry commissioned a leading electronics firm to construct a state-of-the-art apparatus to administer, record, and analyze MC experiments.

1. A little chronology

The term 'Flynn Effect' derives from James Flynn's article in the *Psychological Bulletin* (Flynn, 1984) on 'massive gains' in the mean IQ of Americans from 1932 to 1978. Flynn (1987) followed it with a similar review of 'massive IQ gains' in 14 nations. Then, in the *American Psychologist*, Flynn (1999) discussed the educational and social implications of secular gains in IQ. These articles would probably have remained within the normal purview of psychometrics had Flynn and others not linked the cross-populational phenomenon of secular gains in IQ to the "race issue."

The Flynn Effect remains the most cited and popular idea in the culture-only arsenal. From 1947 to 2002, the developed world saw IQ scores increase markedly–on average, about 3 points a decade for the last 50 years. The mean went up by 18 points in the United States alone on highly *g* loaded tests such as the Wechsler Intelligence Scale for Children (WISC), the Wechsler Adult Intelligence Scale (WAIS), the Stanford–Binet, the Raven's tests, and the Armed Forces Qualification Test (AFQT). Since it was first observed, the secular increase, dubbed the "Flynn Effect" by Herrnstein and Murray in their 1994 *The Bell Curve* (after James R. Flynn who systematized it and brought it to widespread attention), has been proffered as strong evidence that intelligence levels are substantially influenced by environmental factors. As the environment improves in nutrition, schooling, clean air, and public health, IQ scores should increase (especially at the low end of the distribution). If such factors can

* Tel.: +1 707 279 8126.
E-mail address: nesnejanda@aol.com.

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change the mean IQ for the population as a whole, it is reasonable to suppose they could act to narrow the gap between Blacks and Whites. According to Flynn (2008), Black IQ scores in 2008 were higher than White IQ scores in 1950!

Three new books cite the Flynn Effect and the secular rise in IQ in support of the cultural perspective: Richard Nisbett 2009 *Intelligence and How to Get It*, James Flynn 2007 *What is Intelligence?* and Flynn 2008 *Where Have All the Liberals Gone?* Of the three, Nisbett's is the most comprehensive and builds upon the other two. In it, he vigorously renews his earlier critique of Jensen's hereditarian model. While Nisbett now agrees that genes play a significant part in *within group* IQ differences, he contends they play no significant part in *between group* differences. In a technical Appendix, "The Case for a Purely Environmental Basis for Black/White Differences in IQ," Nisbett submitted nine categories of empirical evidence to argue against race-IQ differences being heritable. Rather than interpreting the score gain of 3 IQ points a decade as evidence that people become familiar with test material over time, requiring periodic updates to the test, Flynn and his followers took it to mean that "real" intelligence levels have increased, including abstract reasoning. However, in *The* g *Factor* and elsewhere, Jensen has long pointed out that increased test sophistication and other factors lead to enhanced test taking skills and higher scores and that it is important to disentangle IQ test gains from psychometric g gains. He predicted no significant real-world effects in terms of intelligence. Tests such as the WISC and WAIS lose their *g* loadedness over time with training, retesting, and familiarity.

The reaction in both academia and the popular media to Jensen's (1969) controversial *Harvard Educational Review* article, "How Much Can We Boost IQ and Scholastic Achievement?, set the stage for Flynn's forthcoming role in the story. Unlike many critics, Flynn produced a detailed, wide ranging, critical examination of Jensen's work. Eleven years separated the publication of Jensen's article and Flynn's critique in his, *Race, IQ and Jensen* (1980).

The phenomenon of inter-generational increase in IQ test scores observed in most of the Western world, as essentially discovered and ably described by Flynn (cited above), quickly became eponymized in the psychological lexicon as the Flynn Effect (FE). I have presented my critique and interpretation (Jensen 1998, pp. 318–333). The FE has had an impact in the highly technical field of statistical psychometrics, and probably also in the larger applied field of mental testing in education, the military, employment selection, and clinical psychology.

At a time of increasing attention to IQ variation among subpopulations, the FE promised to absolve the onus of unfavorable social attitudes engendered by these results. The seeming benevolent promise of the FE is that if samples of entire populations in various countries showed secular gains in IQ scores, the lower-scoring subpopulations within these regions would also gain in average IQ. Since the gradual rise in test scores is assumed to approach a saturation (i.e., peak) level, the subpopulation differences in mean IQ should eventually diminish to nonsignificance. Although Flynn did not explicitly make this hopeful surmise, the popular appeal of the FE attracted the interest of experts in psychometrics and statistics. It is through their agency that the greater significance of Flynn's contribution will finally be realized.

The critical point about the FE, however, is the singular fact that both the whole phenomenon and the massive data relating to it are scientifically incapable of answering the essential questions it raises. The central issue is that methodology by which the dependent variable (viz., secular gains in IQ scores) has been measured, fails to meet the standard of the advanced sciences on an *absolutely critical point*! Despite the popular inference drawn from all the IQ data collected, this research can neither confirm nor reject the existence of the FE. Doubling the amount of the already massive data (other conditions being unaltered) could not resolve the issue. But whatever the outcome of a proper investigation of the FE, the gentleman–scholar–philosopher James Flynn deserves recognition as an important figure in the history of psychometrics. The term Flynn Effect, however, will go down in history as a blind alley in psychometrics, viz., trying to answer a basic, nontrivial factual question using wholly inappropriate data.

Suppose a study were performed on the secular trend in the mean height (measured in either centimeters or inches) of 10-year old school children born and reared in a given locality over the past century. The result per se is not controversial and provides a valid basis for research on its causes. Indeed, such studies are among the least controversial findings in the science of human growth and development. Why? Because 'height' can be defined objectively by describing the physical operations used to measure it. The problem with IQ tests and virtually all other scales of mental ability in popular use is that the scores they yield are only ordinal (i.e., rank-order) scales; they lack properties of true ratio scales, which are essential to the interpretation of the obtained measures.

The futility of arguing about the Flynn Effect and related controversies has been well summarized by the professor of mathematical statistics in the London School of Economics:

> "The crux of the problem is that ordinal level measures are not adequate to answer the questions we have posed. Until we have better, brain-based measures of intelligence which measure, at a higher level what *g* and IQ are supposed to reflect, it will be impossible to obtain conclusive evidence." (Bartholomew, 2004).

1.1. Minimum requirements for the scientific study of secular changes in psychometric variables

Four conditions are essential for advancing scientific knowledge about intelligence: (a) clearly formulated coherent *theory* of intelligence; (b) *instrumentation* for the ratio-scale testing of theory-driven hypotheses; (c) a standard *protocol for administering* the use of this equipment; and (d) appropriate *statistical analysis* of the raw data so obtained.

1.2. Comments on the numbered topics listed above

A theory is not itself a true statement or any 'proven' thing. It is a conceptual model or imaginary construction that cannot be verified directly either by logical reasoning or direct physical observation. A *scientific theory* is valuable only to the extent that it can generate specific empirically testable *hypotheses* about some observable phenomenon to be explained. The theory itself cannot be proven true. It can only be tested by confirming or disconfirming empirically the specific hypotheses it generates.

The scientific process, then, consists essentially of: (a) the wholly creative act of *formulating a theory* to explain a particular class of observable, experimentally measurable phenomena; (b) *Deducing hypotheses* (i.e., predictions) from the theory; and (c) *Testing the hypotheses empirically* by appropriate experimental and statistical methods.

2. A new theory of intelligence

2.1. Intelligence is the periodicity of neural oscillation in the action potentials of the brain and central nervous system (CNS)

Operationally this hypothesizes that the typical standard psychometric measures of *g* are correlated with the *oscillation rates* of the brain and CNS as measured by various *Reaction Time* (*RT*) and *Inspection Time* (*IT*) paradigms. (See Jensen, 2006). But first a caution about possibly misleading inferences that could result from the seeming simplicity of this definitional theory, in which the term *periodicity* is absolutely more basic than any of the usual definitions of 'intelligence.' It decidedly should not be confused with Mental Age, IQ, the *g* factor, either fluid or crystallized intelligence, or any other psychometric test score, principal component, or factor score. Rather, the *periodicity* of the CNS is hypothesized as a psychophysically-derived measure.

2.2. RT as an objective measure of CNS periodicity

A separate article would be required to explicate the neurological concept of periodicity, which is inherent in groups of neurons in the CNS. These groups fluctuate periodically in response to incoming stimuli. The fluctuation rate varies across time within any given individual. Popularly called 'brain waves', these fluctuations, when occurring in large groups or systems of neurons, have causes too complex to be as useful for our purposes. So too are the simple response times measured by a strictly overt behavior termed Reaction Time (RT). Rather, we are concerned with the time (measured in milliseconds) that elapses between the presentation of a Stimulus (S) and a person's overt Response (R) to it. Shorter S–R intervals reflect a faster rate of oscillation in neural responsiveness and are therefore the most telling (Jensen 2006; Ch. 11).

Sir Francis Galton (1822–1911), the brilliant younger half-cousin of Charles Darwin, was arguably the most illustrious pioneer in the scientific study of individual differences in human mental ability. Historically, few scientifically interesting phenomena have met with as inauspicious a reception and as many technical problems and methodological blunders as did the early years of research on individual differences in human RT. Nearly every imaginable hindrance to a scientific breakthrough conspired against Galton's conjecture that RT is functionally related to individual differences in human intelligence. Psychometric science's then inadequate understanding of the concepts of reliability, statistical tests of significance, the analysis of variance, correction for attenuation, the progressively diminishing contribution of vast increases in sample size, and the use of components analysis and factor analysis all drastically hindered the scientific development of mental chronometry in the latter part of the 19th Century.

Meanwhile, the clear rationale and obvious pragmatic utility of Alfred Binet's simple tests of a child's 'Mental Age', developed in the early 1900's, so outshone Galton's RT methods in terms of what psychometricians call 'face validity' as to eclipse Galton's theoretical rationale for measuring 'general mental ability'. Binet's practical view of mental measurement has dominated psychometrics ever since, and has indeed proved pragmatically useful in scholastic assessment, personnel selection, and vocational counseling. However, the scientifically more interesting question is what, beyond the obvious face validity, is 'measured ' by an individual's performance on Binet-type tests, which is merely a rank-order score based on the number of test items a given person answered correctly. The person's score *per se* is meaningful only by comparison to the distribution of scores in some defined sample of the population.

It is here that Galton's original concept of measuring the shortest amount of time a person takes to perform an exceedingly simple task, such as simple reaction time to the onset of a stimulus, e.g., a light or a bell, measured in fractions of a second, merits reconsideration. He devised a reaction-time apparatus for this purpose (described briefly by Galton (1908, p. 248) and in more detail by Pearson (1924)). As no formal intelligence tests existed at that time, Galton used the average RT for various educational and occupational categories to test his conjecture that RT is correlated with mental ability. The inconclusive results of Galton's studies appeared not to support his conjecture. If his empirical venture had succeeded, it would have constituted a major scientific breakthrough: the prime desideratum and sine qua non of intelligence measurement on an absolute ratio scale.

History attests that Galton's basic inspiration was worthy of his genius as a scientific innovator. Unfortunately his technical equipment, psychometric procedures, and statistical methodology were all inadequate for the requirements of the research effort required to advance his stroke of genius. The time had not come. The overwhelming null results obtained in Galton's Anthropometric Laboratory in South Kensington, London, in which over ten thousand persons were tested, cast a pall over mental chronometry as a means of studying variation in mental ability.

Galton's idea for a program of RT research was introduced to the U.S. by James McKeen Cattell at Columbia University. It produced the same null result as Galton's laboratory in London. Indeed, additional artifacts were introduced that made matters even worse, so the final analysis yielded a near-zero correlation ($r = -.02$!) between RT and more standard criteria of mental ability. (See Jensen 2006, pp. 5–9 for a summary).

The renewed scientific interest in RT as a precision tool for mental measurement requires a uniform technology to minimize idiosyncratic method variance and other hindrances to attaining a valid science of mental chronometry (see Deary 2000, 2003).

Method variance refers to the systematic variation in a nominal chronometric parameter that results from any differences specific to the apparatuses and procedures used to measure individual differences in nominally the same RT parameters. In my visits to psychological laboratories in the U.S., Europe, and Asia, I was amazed by the extent of variation in research on the "Hick Paradigm" alone. Outwardly, the various apparatuses I examined in different labs scarcely resembled one another. The only guarantee of obtaining standardized measurements accurate in the millisecond range is to standardize the *apparatus*, the *test protocols*, and the *statistical analyses* used. An example from the history of science worth keeping in mind is how the lack of agreement on a standardized, ratio-scale metric for temperature retarded the progress of research in thermodynamics and related phenomena in physics and chemistry for over a century.

2.3. Distinguishing between reaction time (RT) and movement time (MT)

The most damaging methodological mistake in mental chronometry, and probably the most frequent, is the failure to record RT and MT separately. These are operationally defined in stimulus-response terms in four steps:

(1) The Person (P) presses down on the Home Key (HK) for an interval of several seconds while awaiting the imminent onset of the Reaction Stimulus (RS);
(2) The RS occurs;
(3) The Person releases the Home Key, and
(4) Presses the Response Button. The Person's RT is the time interval between (2) and (3). The MT is the time interval between (3) and (4) (Note: RT as defined here is sometimes termed 'Decision Time' [DT]).

The early Mental Chronometry (MC) literature seldom recognized or formally distinguished between RT and MT. Descriptions of the apparatus and procedures are usually too sketchy to infer precisely what was being measured other than possibly some undefined conflation of the two. Faced with this uncertainty, we must distinguish what can be termed nominal RT (nRT). Studies that correlate nRT with any other variable are at the level of correlating random numbers with a specific set of numbers. Any amalgam of RT and MT cannot but attenuate the relation of true RT and other cognitive variables. RT and MT must be measured, recorded, and analyzed separately.

When properly measured, RT and MT are uncorrelated variables. In factor analyses of a wide variety of psychometric and chronometric tests, RT and MT are loaded on entirely different orthogonal (i.e., uncorrelated) factors, with RT loaded on a factor called *cognitive ability* and MT loaded on a factor called *psychomotor ability*. (See Jensen 2006, Ch. 8). The orthogonality of RT and MT would account for the scarcity of substantial and significant correlations between nRT and *g*-loaded cognitive tests. This is likely the main reason that so much of the early MC literature reports meager and nonsignificant correlations with 'IQ' and other psychometric variables. While unrelated to RT, MT deserves investigation in it's own right as a motoric variable.

2.4. Behavioral RT as an indicator of neural oscillation rate in the central nervous system (CNS)

The periodicity and oscillation of electrical potentials in the CNS, commonly called 'brain waves,' is an established phenomenon. Reliable correlations between specific identified brain waves and measures of psychometric *g* have only recently been reported (Jensen 2006, p. 206). The neurophysiology of the human brain has often been deemed too complex to allow the correlation of neural activity and cognition. There are, however, no neurological principles that would preclude it.

For example, a four-step hypothesis can be proposed:

(1) external information enters the brain through one or more sensory channels (i.e., visual, auditory, olfactory, or tactile stimuli);
(2) the brain represents the stimuli, but not as subjectively perceived as a continuous inflow of information;
(3) rather, it encodes the sensory information as discrete bits; and
(4) then decodes that information and produces the appropriate behavioral response.

The amount of time taken by this central coding process is referred to as a '*neural window*' which oscillates at an on–off frequency of less than 100 Hertz (i.e., 100 cycles per second). It is somewhat like the discrete frames of a "motion picture," which must be projected on the screen at a precisely specific rate in order to create the illusion of perfectly continuous motion. By analogy, a person's *focused attention* has a periodic on–off oscillation. It is so fast that it must be measured in milliseconds. An ordinary stop-watch is useless for the on–off rate that causes individual differences in the rate of neural oscillation. It requires a high-speed electronic timer (See Fig. 1).

Information processing speed is theoretically explained in terms of statistically reliable individual differences in the brain's periodicity, i.e., the respective rates of on–off oscillation. The oscillation rate for a given individual determines the size of his neural window for every sensory encounter with the environment.

As shown in Fig. 1, 'Persons' A, B, C, and D differ in their Oscillation Rates (OsRs). Person D has the fastest OsR; A the slowest. As the Information Load (that is, the Cognitive Complexity of the task) increases, as shown by the rising of the upper horizontal line along the Y-axis in the successive panels of the figure, those with faster OsRs are at peak power more often per unit of real time. When the Information Load is the highest (as shown in the final panel), Person D has the most peaks; A the fewest.

Highly accurate and stable measurements of individual differences in RT for various stimuli can be obtained with chronometric equipment specifically designed for this purpose. An operational measure of a person's Oscillation Rate (OsR) is his RT measured in a variety of experimentally controlled conditions.

3. The relationship between RT and psychometric *g*

The Oscillation Theory of Intelligence does not conflict with *g* theory but is an integral aspect of *g*. Oscillation theory is a tripartite formulation embracing three partially overlapping stages of neurological and cognitive development. These stages constitute the crucial period of rapid physical growth and development of the brain and CNS:

Stage 1. Thurstone-scaling procedures that yield ratio scale measurements indicate the CNS neural oscillation that is the progenitor of individual differences in psychometric *g* begins to develop 1 to 3 months prior to birth, and continues at an accelerating rate to maturity. This is the developmental period of

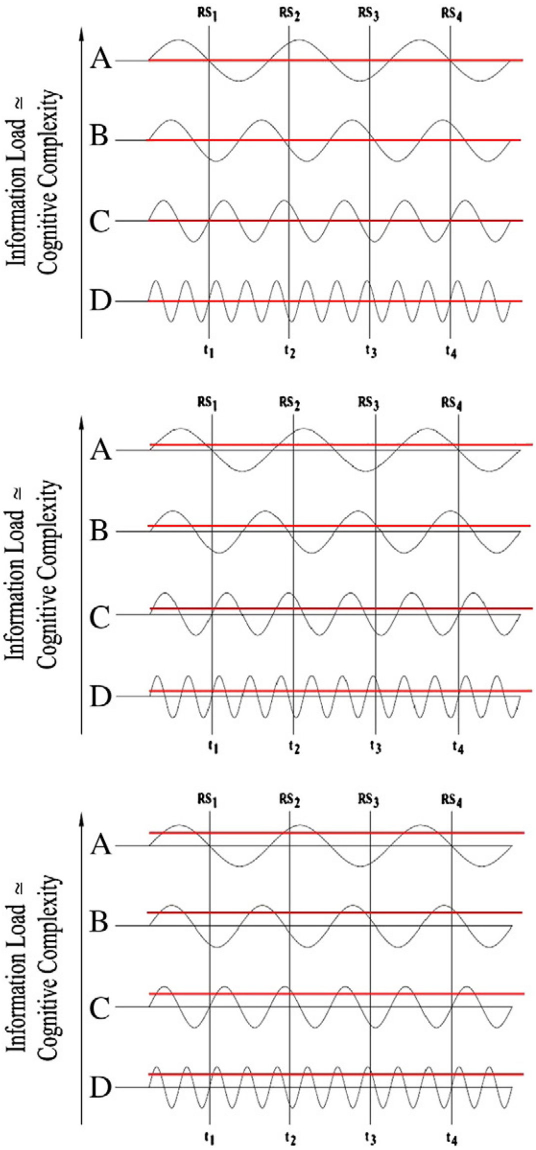

Fig. 1. In the typical RT experiment, the Reaction Stimulus (RS) is presented either randomly or at equal intervals as shown in Fig. 1. The Person's (P's) Reaction Time (RT) is recorded on every trial. The wave of neural excitatory potential for reaction oscillates. It is non-reactive when the oscillating wave of reaction potential is below the person's excitatory threshold (as shown here by the horizontal lines); reactive when above. Therefore, in any random series of RT tests, Persons A, B, C, and D will differ predictably in their respective mean RT in accord with their differing respective rates of neural oscillation. Note in the successive three panels of Fig. 1 that as the Information Load (Cognitive Complexity) of the task increases, the person with the faster Oscillation Rate (OsR) will be at peak power more often per unit of real time.

sensorimotor reactivity to the environment and the momentary focusing of attention.

The comparatively recent and impressively successful progress of behavioral genetics in analyzing the genetic and environmental components of phenotypic variance in mental ability has overshadowed the more detailed analysis of the non-genetic components of fetal development during the period of gestation. An impressive example is a study of 3545 pregnant women whose fetuses were periodically examined during the course of pregnancy to compare differences in the growth rates of various parts of the fetal anatomy. It found that the mother's educational level is correlated with differences in various physical measures such as fetal weight, and the growth rates of various body parts, most notably head size and shape, which showed the highest correlation with mother's educational level. The objectively measured effects remained statistically significant ($p = 0.01$) after the most likely mediating factors were statistically controlled. (Silva, L. M., et al., 2010). The authors concluded: "Low maternal education is associated with a slower fetal growth and this effect appears stronger for growth of the head than for other body parts."

Stage 2. Ages 3 to 4 years: Making sounds and noticing, even briefly, when others in the immediate environment speak or act; can repeat three digits.

Stage 3. Age 5 years and beyond: talks, obeys simple commands; evinces general readiness for beginning kindergarten.

All of the manifest and latent genetic factors involved in the individual's development are present in the zygote as a latent 'genetic blueprint' (*genotype*) which is subject to influence by non-hereditary factors. The genetic plus non-genetic factors constitute the individual's phenotype. The strictly genetic factors latent in the zygote at conception are a product of human evolution, except for rare genes caused by random mutations that have not yet been eliminated by the Darwinian process of natural selection.

3.1. Dynamics of neural periodicity and oscillation speed in behavioral development

Individual differences in the oscillation rates of neural periodicity determine the varying time that different individuals take to learn about common things in their environment. The rate of acquisition of *information*, as this term is defined in information theory, is known as *Hick's Law* (Hick, 1952). It relates RT to the binary logarithm of the number of *bits* of information conveyed in the choice reaction paradigm. The relation of Hick's Law to psychometric intelligence is well-established. (Jensen, 1982, 1987).

The main causal agent in the growth of intelligence begins a few months before birth, presumably with development of the brain's rate of neural oscillation. The oscillation rate (henceforth *OsR*) itself fluctuates in response to internal and external stimuli, so there are statistically significant differences in OsR within persons as well as between persons. This *between/ within* formulation is critical to all research in differential psychology.

The neural oscillation theory comprises a hierarchy of three levels of individual differences:

Level 1. Encoding sensory stimuli. During every waking second the individual's immediate environment is registered, however briefly, by their sensorium: visual, auditory, kinesthetic, olfactory, etc. Attention is the spontaneous or

> specifically directed focus on any particular aspect of the total sensorium. The neonate necessarily experiences the world, as William James so aptly stated, as "one big, booming, buzzing confusion." But along with the further development of attention, the neonate increasingly learns about specific things in its sensory, perceptual, and behavioral environment.

The whole developmental period through childhood and beyond can be described in the technical terminology of learning theory: stimulus, response, reinforcement, stimulus generalization, discrimination, drive, excitation, reactive and conditioned inhibition, trial-and-error, transfer of training, behavioral oscillation, excitatory potential, etc., which we need not describe further here. The important point is that the brain's excitatory potential for any perceptual-motor activity constantly fluctuates and can be measured as *the variance within individuals* and *the variance between individuals*.

Suppose a person's conditioned (or unconditioned) response *R* to a stimulus *S* takes some minimal amount of time that is not known. What we do know, however, is that the individual's entire sensorimotor experience must be a composite result of all the sensory-motor capacities that have developed up to a given point in time. The rate of this development is biologically determined entirely by: (1) the individual's genetic inheritance (i.e., genotype), and (2) the total prenatal environment, which is determined by that individual's overall average rate of brain and CNS periodicity expressed as the CNS oscillation rate (OsR) of the specific neural functions involved in information processing. The *consistency* of individual differences across a wide variety of cognitive behaviors is theoretically the result of individual differences in OsR for each particular activity. (For examples, see Jensen, 2006, Ch. 11).

How is OsR related to psychometric *g*? Every sensory or perceptual event occurring within a conscious perceptible range of focus is registered as a memory in the CNS to the degree of its centrality or proximity to the focal point of the individual's attention. The initial perception, encoded as a smooth flow of events, is actually broken up by random oscillations (OsR) in neural reaction potential. By analogy, a 'movie' is not in motion at all, but is a series of separately-framed still pictures which, when projected serially on a screen at a very specific rate of speed, creates the illusion of smooth, continuous motion.

This example provides a clue to how consistent individual differences in neural oscillation rate (OsR) can account for individual differences in Reaction Time; and conversely, how reliable individual differences (both within and between individuals) in RT can provide a measure of variation in neural oscillation rate (OsR). Exploring the generality and robustness of the OsR across a wide variety of chronometric measures and paradigms is a high priority for future research. The importance accorded to intelligence derives from its positive correlation with differences in many desirable life outcomes including education, vocation, job performance and income. Indeed, measurement of the *g* factor has been dominated by its pragmatic utility in educational and employment selection, rather than by pure research.

The ubiquity of finding essentially the same *g* factor in different, quite diverse, batteries of cognitive tests enhances the credibility of the neural oscillation hypothesis that the cause of intelligence differences is the rate of *spontaneous on–off* oscillations in neural sensitivity. The cause of individual differences in neural oscillation rates that accounts for individual differences in RT also accounts for individual differences in psychometric *g*. Thus RT and *g* are closely related at this fundamental level of analysis. Theoretically, they should ultimately be perfectly correlated but for the 'entropy' inherent in all physical measurements.

Each individual comes into the world possessing all of the de facto and potential behavioral variance that exists in any large population in the world. This latent matrix consists entirely of the genetic and extra-genetic material composing the still developing organism, i.e., the individual human being. Included in this developmental process are the roots of the behavior that becomes recognized as psychometrc intelligence, specifically the *g* factor. Information gained through sensory contact with the environment is processed and brought to bear on further sensorimotor exploration of the surrounding environmental stimulation. The rate and asymptote of mental development are conditioned by genetic factors which account for an estimated 70 to 80% of the total population variance in psychometric *g*.

The chief agency for this development is the degree of the individual's sensory contact with the environment, which in turn depends on the individual's neural oscillation rate, OsR. The more advantaged individuals in this respect are those with higher OsR rates, as it governs the over-all rate of environmental influence. These predictions are borne out in several chronometric and psychometric experiments (Jensen, 2006, Chapters. 6 & 9). The well-established correlations between digit span memory, RT, and IQ fall under the same causal rubric.

4. A note about psychometric *g*

The lower-case italicized letter *g*, also known as Spearman's *g*, along with other formulations of the general factor of a correlation matrix designate the result of a strictly man-made class of mathematical algorithms called *factor analysis* (*FA*). If its workings are not sufficiently understood it can generate confusion and needless argument. One of the aims of FA is to discover the smallest number of independent (i.e., uncorrelated) factors that can account for the correlations (*r*) among a number of superficially different tests. The largest of these factors is termed the general factor (symbolized as *g*). The *g* factor is typically quite similar to what in mathematical statistics is termed the first principal component (PC1) of the correlation matrix, which is calculated by explicitly defined mathematical operations. The only valid basis for controversy is the nature of the data to be analyzed, which is resolved by the chronometric used.

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