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THOMSON'S "BONDS" OR SPEARMAN'S "ENERGY": SIXTY YEARS ON

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The author examines the relative merits of the Binet-Thomson-Guilford theories of intelligence and Spearman's theory of intelligence as "energy" This latter was compatible with Galton's concept of general intelligence as a primarily biological and genetically transmissable reality.

Almost from the beginning of the scientific study of human intelligence, there has been an interesting bifurcation, identified with the names and views of Sir Francis Galton and Alfred Binet (Eysenck, 1985, 1986). For Galton, general intelligence was a meaningful concept, based on biological reality, whereas for Binet it was a statistical artefact, nothing more than the average of a number of semi-independent faculties. Galton stressed the genetic side, Binet the educational and environmental. Last but not least, Galton looked for physiological methods of measurement, instancing reaction time among others, whereas Binet used tasks involving problem solving, learning, memory, etc. As has been well documented (Eysenck, 1979; Vernon, 1979), Binet's methods of measurement were almost universally adopted, and his general views were very widely accepted, particularly in the United States; psychologists in the United Kingdom were more sympathetic to Galton-type ideas. In recent years, there has been a revolution in this field, based on experimental studies of reaction time and evoked potentials as measures of intelligence (Eysenck, 1983), and these studies may cause a reappraisal of the whole situation (Eysenck & Barrett, 1985). A new "model for intelligence" (Eysenck, 1982) seems likely to emerge from these upheavals.

In this paper an attempt will be made to assess to which extent these recent findings are relevant to another theoretical bifurcation, not unrelated to that mentioned above, namely that between the Thorndike-Thomson theory of bonds (Thorndike, Bregman, and Cobb, 1927; Thomson, 1951), and Spearman's theory of "energy" (Spearman, 1927). These two causal theories were put forward in an attempt to explain certain agreed observations in the psychometric field, namely that correlations between cognitive tests were almost universally positive ("positive manifold"), and the resulting matrices tended to have a low rank, possibly rank one. Spearman argued that these facts supported his theory of a general factor of intelligence ("*g*"), whereas Thomson put forward an alternative view which argued that the mind had little structure and that similar psychometric effects would be manifested if "we have a causal background comprising innumerable bonds, and if any measurements we make can be influenced by any sample of that background, one measurement by this sample and another by that, all samples being possible; and if we choose a number of different measurements and find their intercorrelations, the matrix of these intercorrelations will tend to be hierarchical, or at least tend to have a low reduced rank" (Thomson, 1951: p. 271). As he also points out, this is nothing to do with the mind: it is simply a mathematical necessity, whatever the material used to illustrate it. These two alternative views had their origin already much earlier (Spearman, 1904; Thomson, 1916, 1919, 1927, 1935), and they attracted much attention. Mathematicians tended to side with Thomson (Bartlett, 1937, McDonald, 1967; Mackie, 1928), and more recently Maxwell (1972), who made an attempt to resurrect Thomson's theory.

It may at once be said that psychometrically it is impossible to decide between the two theories, as both make similar or even identical predictions. It is possible, however, to make deductions from the theories in question which are *experimentally* testable, and which may give us crucial information concerning the relevance of the theories in question to modern conceptions of intelligence. Let us consider Thomson's theory first, and then go on to recent studies relevant to Spearman's theory.

It is one interesting consequence of Thomson's theory that "if we wish to account for the correlations (between tests) in terms of a single general factor *g*, we assume that *g* is a hypothetical test which requires all the components of the mind" (Maxwell, 1972: p. 4). Generalising Maxwell's statistical development of Thomson's theory, we may say that a test's loading on the *g* factor should be proportional to the number of bonds involved. Alternatively, a test's correlation with a good measure of *g* should be an index of the number of bonds involved in that test. On this basis we should be able to assess at least roughly the *complexity* of a given test (i.e. the number of bonds involved) and predict its factor loading on a *g* factor.

On such a basis, we would expect reaction time measures to show very low correlations with good measures of *g*, such as the Wechsler test, and to have low loadings on a *g* factor derived from complex cognitive measures.

The first of these predictions is clearly not borne out by the facts. As Eysenck's (1986) review of the literature indicates, correlations between tests of choice reaction time of various kinds and accepted measures of psychometric intelligence are quite high when allowance is made for differences in range of talent. (Clearly correlations obtained from populations of a restricted range, e.g. students, have to be corrected for restriction of range, and studies involving retardates are inadmissible, because not only is the range unduly extended, but the possibility exists that retardates react differently to normal subjects). Even for quite short tests, correlations of over .60 can be found between RT and Wechsler IQ (Frearson and Eysenck, 1986). It would be very difficult indeed to account for such high correlations in terms of Thomson's theory of "bonds".

As a study using factor loadings, we may cite Thorndike's (1987) work. He used data originally published by Guilford (1947), consisting of a table of correlations among a set of 65 variables, composed of 45 research tests and the 20 tests of the *Air Crew Classification Battery*. For the purpose of his study, Thorndike divided the first 48 variables into six sets of eight variables that provided the matrix into which each of the remaining tests was inserted, one variable at a time. The *g*-loading of each of the 17 remaining tests was determined 6 times, each time in the context of a different set of reference tests.

One important finding was that regardless of which of these 6 sets the particular Air Crew Classification test was inserted in, its loading on the *g* factor remained strongly invariant, the median correlation over the 6 texts being 0.85. This finding might be explained equally well on Thomson's or Spearman's hypothesis.

It is very much more difficult to explain a second important finding of this study, namely that a discrimination reaction time experiment had average *g* loadings of .52, .55, .61, .59, .60, .61 in the 6 sets of 8 variables within which it was factored, giving a mean value of .58. Of all the classification tests, this gave the second highest *g* loading, higher than those for "reading comprehension", "instrument comprehension", "speed of identification", "numerical operations", "general information", "judgement", or "arithmetic reasoning"! It is hardly arguable that a discrimination time test of the simple kind used makes use of more "bonds" than general information, reading comprehension, or judgement tests! It would seem that these results are fairly decisive in leading to a rejection of Thomson's theory. If we take these facts in addition to the points made by Vernon (1979), namely that already by the 1930s most experimental psychologists were realising that the traditional view of mental processes as built up from associations or stimulus-response bonds was quite inadequate, and that the notion of neurological functioning as a kind of telephone switch-board with each bond dependent on the synapses between particular neurons had proved untenable, we must conclude that Thomson's theory, while ingenious and statistically adequate for its purpose, is psychologically unsound and disproved by experiments.

Within RT data, interestingly enough, there appears to be a very high correlation (+0.95) between mean RTs of 8 different tests and the correlations of these RTs with the tests' correlations with IQ. In other words, "it appears quite likely that the relative complexity of the several RT tests is responsible for the extent to which the tests correlate positively with the *g* loadings of psychometric subtests." (p. 98). This relationship does not obtain for choice RTs using 0, 1, 2 and 3 bits of information arrays (Vernon, 1986).

It had always proved difficult to find any way of testing Thomson's theory, and there has been much agreement with Loevinger's (1951) statement that his theory makes no "assertion to which evidence is relevant." (p. 595). Maxwell, Fennick, Fenton and Dollimore (1974) have attempted to provide positive evidence, but alternative explanations of their results are possible. Willerman and Bailey (1987. in press) have argued that: "results derived from the deaf and the blind individuals affected with Turner's and Kleinfelter's syndrome, and those with XXX aneuploidy all point to the anatomic or functional independence of some verbal and non-verbal abilities. The usual positive correlations between phenotypically different mental tests probably come from concurrently independent, but none the less similarly developing neural machinery". Their evidence is another powerful argument against the Thomson theory.

Let us now turn to Spearman's (1927) view that *g* was ultimately the manifestation of some form of *energy*. He quotes Fechner, Bain, J.S. Mill and Herbert Spencer as earlier advocates of this view, as well as a long list of later writers, including, among others, Woodworth, Woodrow, and Thurstone. None of these authors, however, has put forward a testable and specific theory relating cognitive output to energy, and Spearman himself is quite vague on this point. "Energy", like "bonds", is not presented as a worked-out theory, but rather as a concept that might acquire empirical meaning later on.

The possibility of suggesting such a theory may start with work on glutamic acid, the importance of which was emphasized by Zimmerman and Ross (1944) who reported that feeding of glutamic acid to dull young rats resulted in a considerable improvement in maze-learning ability. Albert and Warden (1944) also reported beneficial effects of glutamic acid on the performance of rats in complex reasoning problems. This work was extended to mentally retarded children, the results suggesting that the acid might increase their IQ as measured by standard intelligence tests. However, not all investigations have given favorable results, as indicated in a review by Hughes and Zubek (1956). Some animal experiments, too, have given negative results, probably because positive results have only been achieved with *dull* rats, so that experiments using average or bright rats are strictly irrelevant to the theory.

These empirical datas are supported by theoretical considerations. Zimmerman, Burgemeister and Putnam (1949) have argued that improvement in learning ability might be due to the facilitatory effects of glutamic acid upon certain metabolic processes underlying neural activity. Thus it is known that glutamic acid is important in the synthesis of acetylcholine, a chemical substance necessary for the production of various electrical changes appearing during neural transmission. Nachmansohn, John and Waelsch (1943) have shown that the rate of acetylcholine formation could be increased 4 to 5 times by adding glutamic acid to dialysed extracts in rat brain, and Waelsch (1951) has shown that the concentration of glutamic acid in the brain is disproportionally high, as compared with the concentration of other amino acids, and is capable of serving as a respiratory substrate in the brain in lieu of glucose. Finally, Sauri (1950), experimenting on rats, discovered that the acid exerts its main effect on the cerebral cortex, lowering its threshold of excitability.

Clearly, glutamic acid is important in cerebral metabolism, and the fact that it is effective in dull rats only suggests that the cerebral metabolism of dull rats is defective in some ways, while that of average and bright rats is normal, allowing glutamic acid to facilitate and improve the defective cerebral metabolism of the dull animals, while having no particular effect on the normal metabolism of the bright ones. This suggestion is strengthened by the fact that Himwich and Fazekas (1940), in a careful study of tissue preparations from the brain of mentally retarded persons, were able to show that these tissues were incapable of utilizing normal amounts of oxygen and carbohydrates. In other words, the cerebral metabolism in these mentally retarded patients was defective.

The later history of what turned into a heated controversy is traced by Spitz (1986), who is relatively pessimistic about the possibility of using glutamic acid to increase IQ in dull humans and rats. He does not report on the latest studies along these lines which give a rather more hopeful aspect to this possibility, as well as forming a link between this work and Spearman's theory

Weiss (1982, 1984, 1986) has recently taken up the general theory of "energy", and cited a number of studies which take further the early work on glutamic acid. Thus IQ has been found correlated with the activity of brain choline acetyltransferase to the extent of .81 (Perry, Tomlinson, Blessed, Burgman, Gibson and Perry (1978), with brain acetylcholinesterase to the extent of .35 (Soininen, Jolkkonen, Reinikainen, Holonen and Reikkinen (1983), and erythrocyte glutathione peroxidase to the extent of .58 (Sinet, Lejeune, and Jerome, 1979). Cerebral glucose metabolism rates have also been found correlated with IQ to the extent of about .6 by DeLeon, et al (1983) and Chase et al (1984). Although these studies were not intended to clarify the physiological background of normal intelligence, but rather to throw light on the metabolic causes of premature senescence and cognitive losses in Alzheimer's disease, Down's syndrome and Parkinson's disease, and normal aging, it is possible to regard these diseases as one tail of a continuous distribution (Mann, Yates, and Marcynik (1984). Furthermore, these correlations with IQ have also been confirmed in healthy comparison groups (Soininen et al, 1983; DeLeon et al, 1983; Chase et al, 1984), and hence the results must be regarded with respect.

In actual fact, the theory offered by Weiss is not dissimilar to that of Zimmerman already refered to. As Weiss (1986) points out, the brain consumes glucose as a normally exclusive source

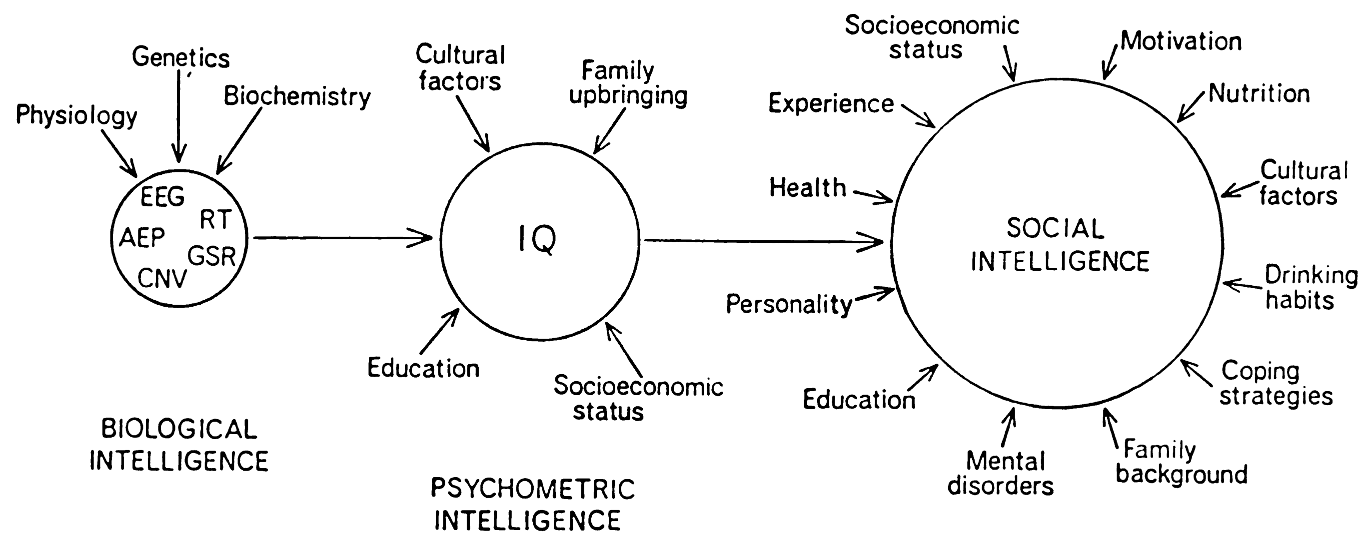

Figure 1: Three different conceptions of "intelligence"

of energy. The human brain represents only 2% of body weight, but its energy consumption is about 20% of total energy requirements (Hoyer, 1982). Compared with a high rate of utilization, the energy stores in the brain are almost negligible, and the brain is consequently almost completely dependent on the continuous replenishment of its glucose supplies by the cerebral circulation (Reneis and Goldman, 1982). Thus it seems reasonable to assume that individual differences in brain power must find their counterparts in individual differences of brain energy metabolism. The argument is strongly supported by the fact that two research groups (DeLeon et al, 1983, Chase et al, 1984) report significant correlations in the neighborhood of .6 between regional cerebral glucose metabolism rates and a number of IQ tests. By positron emission topography of radioactive fluorine it has become possible to quantify glucose metabolism in milligrammes per 100 grammes of brain tissue per minute. The correlations so obtained, since both IQ and glucose metabolism are far from perfectly reliably measured, must be regarded as very high indeed, suggesting a strong degree of dependence of intelligence on cerebral glucose metabolism.

Clearly the data reviewed do not establish Spearman's hypothesis as correct. The numbers involved are too small, the samples are not random, too many of the groups involved are suffering from senile and other diseases, but nevertheless the data are impressive and suggestive. At the moment Spearman's hypothesis appears to have much greater promise than Thomson's for successful elaboration and greater specification of causal mechanisms.

This trend away from the "bonds" theory, and towards "energy" theory is in line with the movement away from Binet, and towards Galton (Eysenck, 1987). It would seem clear that Thomson's notions fit in much better with Binet's model of intelligence than with Galton's, whereas Spearman, who explicitly used Galton's model, would see his concept of "energy" fit in very well with the ideas originally put forward by Galton. Similarly, the notion of energy fits in very well with the genetic type of analysis, the notion of bonds with the more environmentally oriented view.

Another relationship which is of interest is that between the concepts so far discussed, and the Cattell/Horn notion of "fluid" and "crystallised" intelligence (Cattell, 1963; Horn and Cattell, 1966; Stankov, Horn and Roy. 1980). Crystalized ability seems to come much closer as a concept to Thomson's notion of bonds, whereas "fluid" intelligence seems more naturally related to Spearman's theory of "energy" This would lead one to suggest that it is "fluid" ability which is at the center of Spearman's *g*, a view which is strongly borne out by the use of confirmatory factor analysis (Gustafsson, 1984), and the technique of multi-dimensional scaling (Snow, Kyllonen and Marshalek (1984). The very large amount of agreement now apparent in the experimental analysis of intellect makes it apparent that the construct of general intelligence (*g*) is receiving more and more support (Humphrey's, 1979; Jensen, 1984), and although some critics still express doubts (e.g. Detterman, 1982), the downfall of the last large-scale theory to advocate Binet- and Thomson-type views, i.e. Guilford's structure-of-intellect model (Guilford, 1967. Guilford and Hoepfner, 1971) leaves the revised Spearman model (Spearman and Jones, 1950) very much as a main contender in the field (Undheim and Horne, 1977). Clearly we should not aim, as Frederiksen (1986) suggests, "toward a broader conception of human intelligence" (p. 455), but rather concentrate on a better and more fundamental understanding of the nature of *g*.

This point may be clarified by reference to Figure 1, which illustrates three different meanings of the term "intelligence", commonly used almost interchangably, although they are so different that no rational discourse is possible unless it is specified to which of these three meanings reference is made (Eysenck, 1985, 1986). Most fundamental is the concept of biological intelligence, first put forward by Galton as a physiological, biochemical and genetic basis of all cognitive behavior, and all differences in cognitive ability. Binet's notion of psychometric intelligence or IQ is largely determined by biological intelligence, but also by educational and cultural factors, socioeconomic status, family upbringing etc. Finally, social or applied intelligence is to a large extent determined by IQ, but also by a large number of other factors, as indicated in the figure, such as personality, motivation, etc. By being such a complex melange of many different variables, social intelligence has little scientific meaning, and is incapable of being analysed as a unit. Sternberg (1982, 1985; Sternberg and Salter, 1982) seems to adopt social intelligence as the major definition of the term, but his admission that this concept involves personality, motivation and many other factors clearly disqualifies "social intelligence" from being considered a scientific concept. If we accept Sternberg's views, we would have to say that "social intelligence" (as a "supraordinate concept") includes intelligence, personality, motivation etc. among its components, thus using the term "intelligence" in two entirely different senses. If it be true that science always proceeds in the direction of more refined analysis, then clearly biological intelligence is a much more fundamental variable than social intelligence, and theories such as those of Thomson and Spearman are of fundamental importance to a better understanding of the concept. This is not to say that adaptation to social life (which seems to be Sternberg's major definition of social intelligence) is not deserving of analysis; the interaction of the variables indicated in figure 1 is obviously of considerable social importance, and deserves to be studied in detail. What is objectionable is the use of the term "intelligence" to denote this complex of variables, most of which are non-cognitive and non-intellectual.

We may conclude that there is now considerable evidence to favor the model originally constructed by Sir Francis Galton, elaborated by Spearman, and leading to the postulation of "energy" as a fundamental variable in the determination of individual differences in intelligence. On the other hand, the Binet-Thomson-Guilford model has not fared well at the hands of experimentalists, and should be abandoned.

All this is very relevant to the question of the *definition* of intelligence. Ever since the famous symposium that appeared over sixty years ago in the *Journal of Educational Psychology* ("Intelligence and its Measure", 1921), psychologists have tended to define intelligence in terms of some of its *manifestations.* In the original symposium, these range from E.L. Thorndike's definition of intelligence as a "power of good responses from the point of view of truth or fact", to M.L. Terman's "ability to carry on abstract thinking", or R. Pintner's "ability to adapt oneself adequately to relatively new situations in life" More recent studies, including Neisser (1979), Sternberg, Conway, Ketron and Bernstein (1981), and Sternberg and Detterman (1986) have followed this trend. This does not seem to be a reasonable or meaningful way of defining a scientific concept. Physicists do not *define* gravitation in terms of its consequences, such as the apple falling on Newton's head, planetary motions, the tides, the shapes of the planets, the movements of the moon, the bulging of the equator, the existence of black holes, the earth's rate of precession, galaxy formation, the movements of comets, or the existence of asteroids. They define gravitation as that which is responsible for all these events, and clearly no agreement would ever be reached if definitions were phrased solely in terms of the consequences of gravitational forces!

It is for this reason that attempts to define intelligence in terms of mental speed (Jensen, 1982a, 1982b), error rate in information processing (A.E. Hendrickson, 1982; D.E. Hendrickson, 1982), or even more fundamentally in terms of "bonds" or "mental energy" are so important; they provide a link between all the alleged phenomena characterising intelligence.

It may perhaps be advantageous to remember Newton's (1771) famous words in the Scholium (p. 12) preceding his "Mathematical Principles of Natural Philosophy" "I do not define time, space, place and motion, as being well known to all. But it must be observed that the vulgar conceive these quantities, only from their relation to sensible objects. And thence arise certain prejudices, for the removing of which, it is proper to distinguish them into absolute and relative, true and apparent, mathematical and vulgar" The undue concern with popular notions of what intelligence means, which is usually translated into some of the notions mentioned above, is characteristic of the vulgar "relation to sensible objects" What scientists have to do is to strive to overcome this reliance on appearances, and attempt to elaborate theories and definitions that go deeper. This was the original justification for Thompson and Spearman in putting forward their theories, for which at the time there was little evidence. It seems reasonable to suggest that future progress depends crucially on experimental studies testing these theories, and bringing forth evidence to support or reject them.

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