Jensen's Chronometric Research: Neither Simple Nor Sufficient But a Good Place to Start

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Jensen's chronometric research is an outstanding accomplishment that serves as a starting point for research into the many questions that his work has raised. His investigations of the Galtonian notion, that performance on elementary cognitive tasks (ECTs) assessing speed of information processing has significant explanatory value for broad general intelligence, have rekindled research interests in this field world-wide, after almost a century during which the idea was moribund. Two decades after Jensen began his research it is now clear that there is a reliable, moderately strong correlation between various composite reaction time (RT) variables and IQ tests, particularly those generally thought to measure fluid abilities, like Raven's Progressive matrices. Whether Jensen's version of Galton's hypothesis is true or not still remains to be settled.

Powerful arguments against the reification of broad general intelligence as basic speed of information processing are that Jensen's RT task does not simply tap fundamental processes; that a number of independent kinds of speed have been identified; and that these speed factors contribute only some part, along with a number of broad, relatively orthogonal abilities, towards variance in general psychometric intelligence. However, this climate of healthy scientific debate is largely due to Jensen's initiative.

Jensen's contribution to our understanding of the nature of human intelligence has been exceptional, both for the wide range of issues engaged and because of his sustained and prolific published output. His major books and articles covering basic theory about the nature of intelligence, its heritability, its measurement (and particularly his massively, comprehensive book addressing test bias (Jensen, 1980) and, most recently, physical correlates of IQ, should be familiar to most readers. Although it is not central to my assessment of his contribution, without question his comments on average IQ differences between Americans from different racial backgrounds have resulted in a notoriety that has influenced perception both among psychologists and the public at large about the value of

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his other work. It is virtually impossible to draw the attention of students to any part of his extensive research interests without evoking a hostile response to the effect that Jensen is the person who in 1969 lit the fire of controversy about whether genetic factors might substantially underpin Black-White population IQ differences. This being the case, I have found it necessary to warn against throwing out the baby with the bathwater; irrespective of his views on this issue his considerably larger research output relating to other topics in the field is of major importance.

On the question of whether racial differences are substantially genetically determined, I do not agree with him. It is obviously logically respectable to accept that IQ tests are not biased, to accept the predictive validity of *g*, to acknowledge that various abilities including *g* reflect substantial heritability, to accept that Black-White IQ differences are substantially differences in *g*, to recognize that IQ generally demonstrates remarkable stability across virtually the life-span and is very resistant to educational intervention, so that group differences present an extremely persistent, intractable problem—all of which I do—yet still maintain that group IQ differences are probably environmentally determined. One accepts that because of its design (nonrandom selection) and its null outcome Eyferth's (1961; cited by Mackenzie, 1984) study cannot provide a critical test of the environmental hypothesis. However, I find its outcome persuasive nonetheless, as I do Mackenzie's (1984) comments on this matter. Moreover, Flynn's demonstration (see Flynn, 1996, for a recent account) that IQ has been increasing across at least the past 50 years, but without gains in intellectual accomplishment, does question the construct validity of widely used tests. Notwithstanding the longitudinal stability of IQ and the tests' good predictive validity within broad age bands, cross-sectional increase in IQ can only mean that some as yet unidentified environmental circumstances are influencing test performance. I agree with Flynn that currently unidentified socio-cultural factors linked to group membership could retard intellectual development.

Jensen's research interests most closely aligned with my own have concerned his exploration of the age-old intuition, embedded in the language, that "brighter" individuals are "quick witted". This notion, which at one level is probably universally accepted, has nevertheless until recently failed to yield tractable theory accessible to scientific investigation. Psychology on the whole had rejected the suggestion that quickness of thought can either wholly or substantially explain intelligence. Arguments against this have generally been that intelligence involves much more of substantial significance than mental speed (e.g. Horn, 1987), or that correlation does not imply causality and it is at least highly plausible that speed is not a cause but a consequence of intelligence (Mackintosh, 1981). However, Jensen, never one to accept without question the views of even a substantial majority or to shy away from the most controversial issues, has—virtually single-handedly at the outset—forced the psychological community to reconsider seriously Galton's (1883) propositions that intelligence is properly conceptualized as a broad, general mental ability; and that the efficacy of this general ability is determined by the efficiency of fundamental sensory processes.

Of course, Jensen was not the first to address these ideas and his own accounts (Jensen, 1982a; 1987a; this issue) of the beginnings of his involvement with mental chronometry provide informative historical background to his research. He is, however, to this point in time far and away the major contributor to the field.

Initially an advocate for Spearman's definition of *g* as the eduction of relations and correlates, Jensen was puzzled that RT, which did not seem to require complex reasoning, should correlate with IQ at all. Galton's broad general ability arising from basic processes was more accommodating, however, and the speed of such processes could account for Spearman's observation that specific test content was largely unimportant for measuring intelligence ("the indifference of the indicator"). If all intelligent activities are dependent on the resources of an information processor with limited capacity to cope with input at any point in time before reliance on long-term retention, then more rapid encoding and storage must bestow advantage; a faster processor should be capable of more accurate mental activity and therefore greater knowledge acquisition per unit time. In order to test his working hypothesis that intelligence reflects speed of information processing, Jensen first defined intelligence as "psychometric *g*" (i.e. a principal or higher order factor extracted from a battery of diverse psychometric tests) and operationalized this in terms of marker tests, principally Raven's Progressive Matrices. Secondly, he operationalized speed of processing in terms of various parameters of reaction time (RT). As he has acknowledged (Jensen, 1982a; this issue), his version of Galton's hypothesis has widely been regarded as highly counter-intuitive; one may accept some kind of relationship between speed of thought and intelligence but to attempt to explain the complexity of the latter in terms of a task with such apparently trivial knowledge requirements as RT has stretched credibility for many. For this explanation to be correct requires that processes producing simple and choice reactions are essentially those governing complex intelligent behavior. I was in the audience at a NATO (Human Factors) International Conference on Intelligence and Learning, held at York, England, 1979 when Jensen made an early presentation of his RT research begun in the early 70s (see Jensen, 1981). Aside from my interest in the substance of his talk, I have since carried two enduring impressions from that meeting. The first is of Jensen's resolute commitment to his viewpoint, based on his systematic theoretical approach, in the face of savage criticism of his work from the body of the audience and his courtesy when responding to that criticism. The second is of the late Neil O'Connor's subsequent comment to me, to the effect that time would vindicate Jensen's claim that there is a theoretically significant relationship requiring explanation between psychometric tests for intelligence and RT. Because I long regarded Neil O'Connor as one of the most perspicacious persons I have known, I have not been surprised that this prediction has substantially been met.

Jensen's RT Research

Jensen has described his research, done between the early 1970s and mid 1980s, in several reviews (Jensen, 1981; 1982a; 1982b; 1985; 1987b; 1992). Jensen (1982a) briefly reviewed others' applications of RT methods aimed at testing dimensions of memory (e.g. S. Sternberg's variable set, memory scanning procedure, Posner's letter matching task) to the investigation of intelligence and at least one study from his laboratory (Vernon, 1983, N=100) has used variants of these. However, most commonly Jensen has used an apparatus (see Jensen, 1987, Figure2) now frequently referred to in the literature as the "Jensen button-box" but much earlier used, if not devised, in the early 1940s by Goldfarb, who was at Columbia University ahead of Jensen, and by Miles (see Welford, 1980; 1958 respectively). This apparatus presents the subject with a configuration of up to eight stimulus

lights arranged in a semicircle to be equidistant from a home key. A trial begins with the home key depressed by the forefinger of the preferred hand. Degree of choice is manipulated across conditions, with the required reaction triggered by illumination of one signal. This apparatus times the latency of release of the home key following signal onset (RT) and movement time (MT) between home-key release and depressing the specified signal key. Within-subject conditions with 1, 2, 4, and 8 signal alternatives generate RT and MT data as a function of choice (n), expressed as bits ($\log_2$ n) of information (Hick, 1952). As predicted by the theoretical distinction between RT and MT, mean group RT generally conforms well to Hick's Law and MT does not, being relatively stable across choice.

Jensen (1987b) has provided the major comprehensive review of 33 studies, involving 2317 subjects, that have followed the Hick procedure. Twenty four of these studies were completed by Jensen and his associates but all samples were independent. This impressive data bank has continued to provide Jensen with opportunities for further data analyses over the past decade (e.g., Jensen, 1992; 1998)

Jensen has tested for a relationship between IQ and various chronometric variables derived from RT (and MT) in two ways. First, comparisons have been drawn between groups with different average levels of IQ. Second, chronometric variables have been correlated with IQ within samples. Applying multiple regression, various combinations have been explored to arrive at an optimal set of predictors for IQ. Chronometric variables have frequently been experimentally dependent, being obtained from the same data, (e.g. slope and intercept of the regression line, median, SD) but have sometimes made unique contributions to IQ variance explained. However, although virtually all studies have found within-subject variability in RT to be the strongest single predictor of *g*, across studies the optimal set has not been consistent. Moreover, some results have not been consistent with the hypothetical separation of decision making from psychomotor processes, as envisaged by the RT-MT distinction. Although independent within subjects as predicted, RT and MT have been found to be significantly correlated across subjects, so that on occasions - and contrary to theoretical prediction - variables derived from MT have contributed significantly to the prediction of IQ.

These outcomes have meant that it has not been possible to explain the RT-IQ correlations in terms of the hypothetical psychological processes that at the outset were assumed to be captured by particular chronometric variables. Moreover, results have generally not upheld the construct validity of such processes. For example, prior to Jensen's research the slope of the Hick function had widely been accepted as measuring the rate of decision making processes, whereas the intercept was supposed to represent both sensory input and response organizational aspects of processing. Theoretically therefore, slope would be expected to be the more robust predictor of IQ. Such has not been the case, however - although Jensen (1998) has recently argued that this is because the expected correlation with IQ is suppressed by statistical artefacts arising from, among other things, the low reliability of the slope mean. This analysis, completed about a decade following the 1987 review, finds the theoretically expected slope-IQ correlation - and demonstrates Jensen's persistence and ingenuity when faced with a problem. His account (Jensen, 1987a; this issue) of how he became involved in issues of test bias and the genetics of intelligence illustrates his determination to inform himself as fully as possible about any subject undertaken. His scholarship is formidable and he never leaves an untidy conceptual loose end until the matter has been resolved to his satisfaction).

From the outset of his investigations into Galton's hypothesis, Jensen has followed the same procedures, despite a range of criticisms directed against them (see, for example, Longstreth, 1984, and various commentaries to Jensen, 1985). I agree with his position (this issue) that maintaining a uniform method was the appropriate strategy and, by insisting on this, he has succeeded in accumulating a valuable data set. Attempts to investigate a speed-IQ relationship with an alternative task, inspection time (IT), have been encumbered by the procedural variations of different researchers (Nettelbeck, 1987).

Jensen has been assiduous in attempting to address criticisms and he has accomplished this with varying success. By doing so he has built up a valuable, empirically determined body of knowledge about the nature of the RT-MT task that did not exist before he began his research. Concerns about lay-out configuration for stimuli, order of choice conditions, practice effects and so on are obviously of consequence; but the fact is that Jensen's finding of moderate correlation between RT-MT variables and IQ appears to be robust. He has estimated that the multiple correlation across chronometric variables within a normal IQ distribution is as high as -0.7. My expectation, based on IT research (Deary & Stough, 1996; Kranzler & Jensen, 1989; Nettelbeck, 1987) is that -0.5 will eventually be accepted as about right. (Although RT and IT apparently measure different things to some extent, they share common IQ variance).

Moreover, Jensen's comparisons between groups selected on the basis of average differences in IQ have also provided compelling evidence for a moderate negative relationship between RT-MT variables and IQ. This finding has not been simply the outcome of comparisons between intellectually disabled and nondisabled groups but has been found for IQ comparisons involving average, above-average and gifted children, university students versus vocational college students and exceptionally high IQ individuals versus university students. In summary, therefore, Jensen has convincingly demonstrated that the level of correlation between variables indexing speed of mental reactions and IQ is theoretically substantial and appreciably higher than had been predicted by earlier research (Hunt, 1980).

What Does the RT-MT Correlation with IQ Mean?

Jensen has proposed that at the psychological level RT provides an index of information processing that is related to IQ. If this is so, then increasing correlation between IQ and RT is predicted as the information processing demands of the test situation increase. This prediction is nicely confirmed (Jensen, 1987b). However, to extrapolate beyond this to theory about the number and activities of neural cells is unlikely to be fruitful at this stage, because of the shortcomings in construct validity of the RT-MT method, as outlined above. Jensen (1982a) has demonstrated that RT is at least substantially more an index for decisions based on uncertainty, relatively independent from response selection requirements but Smith and Carew (1987) have clearly demonstrated that the RT-MT task is subject to the influence of cognitive strategies. Moreover, even these authors' modification, which introduces a backward masking procedure to Jensen's standard method as the means for discouraging the strategy of using MT to reduce RT, cannot completely obviate such "hovering". My impression, based on extensive experience with the task, is that memory for stimulus position is not eradicated by the mask. No one yet has with this task addressed Rabbitt's (1968) finding with conventional choice RT (i.e., choice alternatives match

response selection across fingers) that participants continuously monitor their responses while maintaining acceptably low error rates. Nonetheless, I would confidently predict that Jensen's task will be found to be influenced by higher-order cognitive processes in the same way. Although commonly referred to by those working in the field as "elementary cognitive tasks" (ECTs), RT procedures are only elementary in the sense that they certainly present relatively low knowledge requirements for participants, compared to most items in traditional tests of cognitive abilities. They therefore have a long history as outcome variables exploited to reveal the nature of psychological functions. However, it is not the case that ECTs require only basic mental capacities and exclude the operation of more complex intellectual functions.

This being so, optimism about ECTs as replacements for current psychometric tests of cognitive abilities is not warranted. Reflecting on the future of psychological testing and assessment during the first two decades of the 21st century, Matarazzo (1992) has predicted the practical application of what he termed "biological indices of brain function and structure" (p. 1012), by which he meant parameters of performance drawn from the electroencephalogram (EEG), from RT and from IT. Having considered the literature on these topics during the previous decade or so, Matarazzo was convinced that such measures have the potential to serve in the relatively near future as practical measures of intelligence. I disagree with this assessment. Such measures are not biological; they are psychological. Even EEG, which many psychologists regard as essentially physiological, may be influenced by personal factors including motivation and mood (Callaway, 1975). For another thing, although ECTs provide useful tools for the advancement of theoretical explanations about the psychological nature of intelligence, they are insufficiently reliable to permit accurate assessment of individual differences in cognitive abilities - because of practice effects, probably inherently so. Moreover, as discussed below, it is unlikely that speed of information processing can provide a sufficient explanation for intelligence.

As far as I can recall, Jensen has not speculated about the practical application of chronometric tests for individual differences in *g*, his concerns from the outset always being focussed on future theoretical development (Jensen, this issue). As he has previously acknowledged (Jensen, 1987a), the Galtonian position has provided him with no more than a falsifiable working hypothesis which, consistent with the goal of parsimonious explanation, he has been prepared to advance by empirical investigation as far as he can. For this he deserves considerable credit and I share his enthusiasm for the quest. However, I am unwilling to accept that ECTs are simply as basic as Jensen has sometimes seemed to assume. Until the recent advent of neurophysiological imaging procedures, ECTs have been the tasks best suited to Jensen's purpose that we have had; but we do not know that ECT-IQ correlation reflects only shared basic processes. I agree with his conclusion (this issue) that we do not yet know that mental speed is.

Intelligence is More than Mental Speed

Wilson, Nettelbeck, Turnbull, and Young (1992; Nettelbeck & Wilson, 1994) have suggested that speed of information processing may be a necessary component to an explanation for intelligence but is not sufficient to account fully for individual differences in intellligence. Kail's (1992) comprehensive review of RT throughout childhood has shown that RT improves until about 11-14 years of age, after which it is more or less asymptotic

at young adult levels. Nettelbeck and Wilson's (1985) cross-sequential analysis of childhood IT is entirely consistent with this. However, mental age obviously goes on developing beyond adolescence. Moreover, some individuals with IQ scores in the retarded range have short ITs, inconsistent with their low IQs. Several other authors have emphasised that a moderate correlation between RT and IQ does not establish that mental speed provides a sufficient explanation for intelligence (Detterman, 1987; Horn, 1987; Juhel, 1991; Mackintosh, 1981; Marr & Sternberg, 1987; Rabbitt, 1996).

Stankov and Roberts (1997) have recently presented a most formidable challenge to the intelligence-as-speed proposition. Firstly, they point out that no one has yet literally tested this proposition because RT studies, including Jensen's, have not actually extracted a measure of *g* from a diverse battery of cognitive tests. Instead, researchers have relied on a single test like Raven's Progressive Matrices, which is widely accepted as a marker for Cattell's G_f. Consistent with Carroll's (1993) "three-stratum theory", the second stratum of which is essentially occupied by the broad abilities identified by the Horn-Cattell theory (Horn & Noll, 1997), Stankov and Roberts insist that Raven's Matrices are not an adequate test of the broad general factor. Moreover, although speed factors at the second stratum are important aspects of intelligence, several other factors are equally critical to an adequate description of intelligence. They point also to Carroll's (1994) conclusion that the third-stratum general factor is defined more in terms of levels of complexity rather than speed of processing.

Secondly, Stankov and Roberts (1997; see also Roberts & Stankov, 1997) argue that speed is factorially complex and they therefore reject speed as a basic construct. This argument is convincing. Their evidence, drawn from Roberts (1995), is that mental speed is not restricted to the two broad speed factors within $G_f - G_c$ theory (i.e., G_s and Correct Decision Speed). Robert's detailed factor analyses of 25 psychometric tests used to model the $G_f - G_c$ theory, together with 11 ECTs to explore dimensions of speed, result in a tentative revision of Carroll's (1993) theory in which many separate speed factors are differentiated. These form a hierarchical structure, from narrow-based factors through broad factors to a second stratum general cognitive speed factor. Consistent with Carroll (1994), above, reliable correlations involving ECTs were limited to G_f.

Conclusions

Carroll's three-stratum theory is consistent with Jensen's adaptation of Galton's suggestion that intelligence can be represented as a broad general factor, although an adequate description requires much more than a single test like Raven's Progressive Matrices can contribute. Jensen's choice of a test to operationalise intelligence was therefore too narrow. Moreover, mental speed measured by the RT-MT task is not unitary and the task does not simply tap basic speed, in the sense of fundamental, biological processes. Obviously Jensen has acknowledged the nonunitary nature of his task by seeking to separate RT from MT and by using composite chronometric variables when exploring correlations with IQ. However, this attempt has not revealed a common set of chronometric variables that reliably predict IQ.

Nonetheless, Jensen's chronometric research is a considerable accomplishment. He has provided by far the single most substantial body of data based on a single innovative procedure and he has demonstrated beyond question that there is a much stronger correla-

tion between RT variables and IQ than modern psychology, until his involvement, had entertained. Criticism aside, there is something there to be explained. As a direct consequence of his many publications on the topic, there is now considerable renewed interest world–wide in Galton's proposal that mental speed is an important causal factor underpinning the development of intelligence. Along the way he has added considerably to our knowledge about the nature of RT, including the previously little recognised possibility that within–subject variability rather than mean RT is critical for explanatory purposes. I agree with his assessment (this issue) that although he has not proved his version of Galton's hypothesis, it still has not been refuted.

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