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ABSTRACT

General intelligence ("g") is one of the most important, and least understood, phenomena in psychometric psychology. Yet "g" is an issue that is largely ignored in cognitive studies of aptitude. In the current paper, an attempt is made to bridge the gap between psychometric data and cognitive theory, using two major performance frameworks (structural and resource/capacity frameworks). Neither framework explains all phenomena related to general intelligence. The concept of "attentional resources" is currently the most viable cognitive analog of "g". It is unlikely that "g" is merely a complete set of elementary cognitive components. More likely, intelligent performance depends on both activating resources for thought and strategies and knowledge affecting the allocation of those resources. Clearly, resources and strategies are both involved in any individual test score. It is conceivable, however, that resources are primary to "g". (TJH)

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Cognitive Frameworks for g

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Abstract

General intelligence (g) is one of the most important, and least understood, phenomena in psychometric psychology. Yet g is an issue that is largely ignored in cognitive studies of aptitude. In the current paper we attempt to bridge the gap between psychometric data and cognitive theory, using two major cognitive performance frameworks. We conclude that the concept of "attentional resources" is currently the most viable cognitive analog of g.

The opinions expressed are those of the authors, are not official and do not necessarily reflect the views of the Department of the Navy or the U.S. Government.

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Purpose

In the current paper we propose that an explanation of general intelligence (g) is one of the most significant challenges facing cognitive psychologists. We then suggest ways in which cognitive performance frameworks may be applied to the study of g.

Background

Cronbach (1957), in a now famous address, stressed that experimental methods could be used to build construct validity into test theory. The desired result of this merger was a mental process explanation of test results. Despite Cronbach's proposal, progress in the experimental tradition has, in certain respects, side stepped fundamental issues in correlational or psychometric psychology. The construct of general intelligence exemplifies this continued schism. Psychometric data support the conclusion that general intellectual ability provides most of the predictive power of aptitude batteries (Humphreys, 1979; Hunter, 1983a; Jensen, 1984; McNemar, 1964; Thorndike, 1985; Vernon, 1950). Hunter (1986), for example, notes that the massive data bases gathered by the U.S. Employment Service and the Armed Forces clearly suggest that it is general cognitive ability rather than specific cognitive aptitudes that predict job performance. Jensen (1986) has broadened the discussion by demonstrating that g, in addition to having significance for vocational screening, is related to a number of biological indices and performance on elementary reaction time tasks.

While g, or variance shared across tasks, is thus a central issue in psychometrics, the experimental tradition most often involves the study of single tasks or aptitude constructs. Many single task studies, by design, further compartmentalize performance into a lawful set of processing stages or components. The final cognitive models, while fulfilling the experimenter's purpose, are not suited for cross reference and thus do not easily explain task intercorrelations. As an example, the correlational literature indicates that a moderately strong relationship exists between mathematical and spatial abilities. Information processing descriptions of math and spatial tasks, however, have few common components that would explain the convergence of these aptitudes (Briars, 1983; Lohman & Kyllonen, 1983). The challenge, then, is to determine whether experimentally derived views of task performance are of any use in understanding the fundamental basis of test validity, i.e., g.

Toward a Cognitive View of General Intelligence

It is almost certainly critical to observe that g is empirically related to a dimension of cognitive task complexity. Marshalek, Lohman, and Snow (1983), for example, compared radex and hierarchical models of ability and concluded "the actual correlation between a test and g approximates the apparent complexity of its required cognitive operations" (p. 108). Also, the predictive validity of general cognitive ability is positively correlated with the complexity of the criterion task (Hunter, 1983b). That complexity has a ubiquitous role is further demonstrated by data on reaction times. Cohn, Carlson, and Jensen (1985) compared the performance of psychometrically gifted and nongifted subjects on a number of reaction time (RT) tasks. They report a correlation of .94 between the complexity of the RT task (as indicated by mean latency) and the magnitude of group differences in performance.

A critical question, then, is whether current cognitive theories can explain how g manifests in relatively more complex tasks. Following Sanders (1983), we recognize two major cognitive frameworks of performance: Structural (or linear stage) models and energy resource (or capacity) models. The structure and resource models support different explanations for the relationship between task complexity and g.

1. Cognitive Structures. Structures include the concepts of processing stages (S. Sternberg, 1969), components (R. Sternberg, 1980), and other descriptors for the elementary functional units of cognition. These elementary components are coordinated by executive or metacomponential routines (Hunt, 1980; Sternberg, 1980). The component/metacomponent hierarchy allows at least two structural theories of g. (1) Component sampling theory. Let g be the universe of components (see Detterman, 1986), and correlations with g the extent to which the universe is sampled. Thus, more complex tasks, which include many cognitive components (Vernon, 1985), are the best measures of g. (2) Metacomponential theory. Since metacognition is mental self-government (e.g., Sternberg, 1985), this form of a structural theory involves a strategy-based explanation for g. One assumes that more complex tasks are amenable to a relatively greater variety of possible approaches, and g reflects the general tendency to employ efficient strategies across diverse tasks.

2. Energetic resources. "Resources" is a term sometimes applied to the finite pool of energizing forces deployed in cognitive tasks (Gopher & Donchin, 1986; Wickens, 1984). In Engineering Psychology, increases in operator workload require increased resource investment (e.g., Wickens, 1979). Performance breaks down when the resource pool is exhausted. The concept of "workload" may also apply to mental test items. For example, if task complexity stems in some measure from problem size (the number of problem elements and their transformations), it is partly because the problem solving workspace (e.g., short-term or working memory) is a limited capacity system. But what is capacity? Hunt has hypothesized that "short term memory capacity...is not a direct measure of a structure used in problem solving; rather, it is an indirect test of the availability of the attentional resources required for...thought" (1978, p. 117). Thus, individuals may vary in their ability to supply an activating force which enlivens short-term memory representations and powers their transformations.

Evaluation of Frameworks

An evaluation of structural and resource/capacity frameworks indicates that neither readily explains all the phenomena related to general intelligence. Component sampling theory must lead to a taxonomy of components which are uncorrelated with one another, and differentially correlated with psychometric task performance. The latter follows since any "whole" (a psychometric test) should correlate with its parts (relevant cognitive processes), but not other measures. As yet there are no such component taxonomies with promising convergent/divergent validities vis a vis psychometric batteries. The literature further indicates that many elementary cognitive measures are intercorrelated (Jackson & McClelland, 1979; Keating & Bobbitt, 1978; Kyllonen, 1985; McGue, Bouchard, Lykken, & Feuer, 1984; Lansman, Donaldson, Hunt, & Yantis, 1982; Paul, 1986; Vernon, 1983; Vernon, Nador, & Kantor, 1985; also see Cooper & Regan, 1982), raising doubt about theories which suggest process independence. Finally, it is simply not obvious that common operations produce correlations across broadly diverse tasks. The theory would appear to have difficulty explaining how a visual encoding task like Inspection Time correlates with Vocabulary scores (Lubin & Fernandez, 1986), and how a "verbal correlate" like speed of letter naming (Hunt, Lunneborg, & Lewis, 1975) correlates with Ravens scores (Ford & Keating, 1981).

Though studies show that metacomponents or strategies affect performance on cognitive tasks (e.g., see Brown, Bransford, Ferrera, & Campione, 1983; Lohman & Kyllonen, 1983; Underwood, 1978), the implications for general intelligence are unclear. A fundamental issue concerns description versus explanation, and which characterizes the observation that high ability individuals choose more efficient strategies. When tasks are novel, the spontaneous choice of an effective approach seems to raise as many questions as it answers. We will return to the role of strategies in test performance shortly.

A resource/capacity theory of g fits quite nicely with the view that "problem size" (Bourne & Dominowski, 1972) is a source of task difficulty. For example, Kotovsky, Hayes, and Simon's (1985) analysis of the Tower of Hanoi problem indicates that increased memory load is a major reason why some versions of the task are more difficult than others. Mulholland, Pellegrino, and Glaser (1980) found that the difficulty of geometric analogy problems was related to the number of elements defining the test items and the number of transformations on those elements required by the problem. Each operation for defining and transforming elements was said to take up space in memory, with the aggregate being related to errors and increased solution time in a multiplicative rather than additive manner. The interaction implies competition for common memory resources. Hitch's (1977) experiments on mental arithmetic indicated that errors occur due to memory loss, which itself is a function of the number of operations. An analysis of spatial abilities by Lohman (1979) indicated that tasks which require simultaneous memory demands and data transformation are more intellectually demanding than tasks requiring either one alone. Limitations in memory capacity have also been related to deficits in reading skill (Baddeley, Logie, & Nimmo-Smith, 1985; Daneman & Carpenter, 1982), performance on figural matrices (Stone & Day, 1981), difficulty of letter series problems (Kotovsky & Simon, 1973), and reasoning from new information (Light, Zelinski, & Moore, 1982). Also pertinent is a study by Jensen and Figueroa (1975), who found that performance on backward digit span is more highly related to IQ than performance on forward digit span. One might speculate that greater problem size (e.g., processing and/or memory demands) under the backward condition causes the incremental loading on intelligence.

Problems with the resource view of intelligence include its application to crystallized intelligence. Vocabulary, for instance, is a good index of g (Jensen, 1980). Possibly, knowledge retention is related to the amount (or intensity) of attention invested in processing (see Geiselman, Woodward, & Beatty, 1982). Still, other data remain problematic, including questions regarding the number of energetic resource pools (see Wickens, 1984), and the implications of the Yerkes-Dodsen law (1908), which portrays energetic/performance relationships as nonlinear.

A resource theory must also refer to allocation policies, which are synonymous with metacomponents or strategies. If g is a resource pool, then no single aptitude test is a pure capacity measure because single test scores are contaminated by factors of resource allocation (i.e., strategies, automaticity of task components, chunking, etc.). In a g-factor score, however, it is likely that test-specific allocation policies wash out. The fact that g has greater predictive validity than single tests (Hunter, 1983: Jensen, 1984; Thorndike, 1985) is perhaps evidence that strategies are sometimes a source of error variance in mental measurement (in that they obscure the assessment of capacity), rather than a source of test validity.

Concluding Remarks

We are not at all convinced that g is merely the complete set of elementary cognitive components. More likely, intelligent performance depends on both activating resources for thought and strategies/knowledge affecting the allocation of those resources. Clearly, resources and strategies are both involved in any individual test score. It is conceivable, however, that resources are primary to g (Ackerman, 1987). Though the present paper is admittedly speculative, we hope at least to inspire further debate among experimental psychologists about a phenomena that is of substantial real world importance.

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