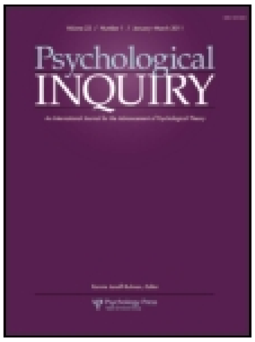

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A *g* Theorist on Why Kovacs and Conway's Process Overlap Theory Amplifies, Not Opposes, *g* Theory

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Kristof Kovacs and Andrew Conway (this issue) raise a question that *g* theorists have sought to answer since Spearman (1904) statistically demonstrated the existence of the general intelligence factor, *g*, more than a century ago. Namely, what in the particulars of brains and biology could generate such a domain-general (content-independent) cognitive tool in everyday life? Like the great pioneers in *g* theory—Charles Spearman (1863–1945), Hans Eysenck (1916–1997), and Arthur Jensen (1923–2012)—Kovacs and Conway seek to understand the underpinnings of *g*'s domain generality by looking into the more elemental processes by which brains process information. I am pleased that these talented cognitive scientists are joining the effort.

They argue that their theory is superior to prior explanations, with special attention to *g* theory. They dispute a series of crucial claims that they associate with *g* theory, showing how the evidence is more consistent with their own theory. But the *g* theory they portray is not the one to which *g* theorists actually subscribe. The good news is that process overlap theory amplifies *g* theory exactly where its pioneers searched hardest for answers—in how the mind and brain process information to learn and solve problems.

My commentary explains why their contributions to understanding intelligence are concordant with, not contrary to, *g* theory. I do so by summarizing the contrasts they draw between their overlap theory and *g* theory, and how the seeming discordance is resolved by distinguishing between different levels of analysis in the full body of evidence on what *g* is and is not. I also suggest a strategy for simultaneously advancing the two theories, specifically, by exploiting a key "trait" of tests and tasks—their relative complexity—that activates the domain-general processes and abilities of keen interest to both. I draw on my work as a *g* theorist (Gottfredson, 1985, 1986, 1997a, 1997c, 2002a, 2002b, 2004, 2007, 2011). Although trained in sociology, my inquiries into the roots of social inequality and job aptitude demands led me inexorably to *g* (Gottfredson, in press).

Process Overlap Theory Offers an Alternative to *g* Theory for Explaining Psychometric *g*

The authors propose a new explanation—process overlap theory—for the "most replicated result in the field of intelligence" (p. 151). As Spearman discovered long ago, all cognitive tests correlate positively with each other, regardless of their manifest content (verbal, figural, etc.) or format (written, aural, individually or group administered, etc.). In technical jargon, mental tests exhibit positive manifold. In practical terms, individuals who perform well on one mental test tend to perform well on all others. In theoretical terms, *g* represents the most generic mental capacity possible: an all-purpose cognitive tool that enhances performance on all tasks requiring any mental manipulation of information. Spearman developed a statistical technique, factor analysis, to quantify the shared overlap (covariation) among mental tests, extract their common factor (*g*) for study as a phenomenon in itself, determine how well each test measures it (the test's *g* loading), and calculate test takers' relative standing (*g* scores) on this latent trait. He did so not to develop tests of intelligence but to understand this most astonishing phenomenon.

Kovacs and Conway, however, depart sharply from this conception of *g* because they do not regard *g* as a phenomenon in its own right. In their view, the general factor exists only as "a necessary algebraic consequence" of the positive manifold among tests. Under process overlap theory, "what is discarded is '*psychological g*': the interpretation of psychometric *g* as a psychological construct" (p. 241). In other words, the *g* factor is not an indicator of "general intelligence," as *g* theory holds, but merely a description of the positive manifold among tests' scores when quantified by factor analysis. The authors' aim, therefore, is to explain the positive manifold, not the algebraic representation of it as a unitary general factor.

To do so, they propose that many discrete cognitive and neural processes interleave—"overlap"—for individuals to answer test items correctly. Only mental processes that are globally useful (domain general) will contribute consistently to the positive manifold observed among tests of diverse content. Their overlap theory thus draws on information-processing constructs of this sort from cognitive psychology (working memory, executive function, attention, inhibition), cognitive neuroscience (the connectome, small world networks), and intelligence research (fluid *g*, reasoning). Conversely, tests of domain general constructs exhibit what Spearman (1927, p. 197–198) called "indifference of the indicator," meaning they line up individuals in basically the same order regardless of the tests' intent or appearance. To illustrate, tests of verbal ability and mathematical reasoning are for many purposes functionally equivalent because both measure mostly differences in *g*. That is why both are almost as good in predicting performance

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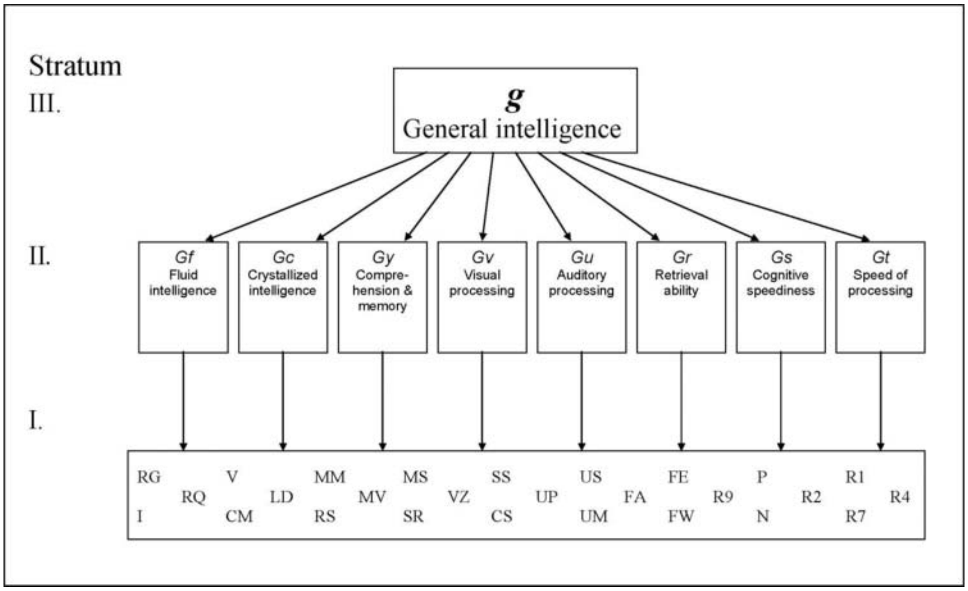

Figure 1. Carroll's (1993) three-stratum model of human cognitive abilities.

in the other's content domain as their own. As Kovacs and Conway (this issue) point out, what "a test a *purports* to measure" is not necessarily what it actually does measure (p. 165).

They argue the superiority of their theory by contrasting it with other explanations of this functional overlap among mental tests. They briefly describe several theories that likewise eschew a general factor, the best known being Thomson's (1916) sampling theory. They focus their contrasts, however, on the theory that gives the *g* factor a starring role in intelligence—*g* theory. To explain their departure from *g* theory more clearly, they refer to Carroll's (1993) three-stratum model, which organizes humans' many cognitive abilities according to their relatedness and scope of application. Figure 1 illustrates how his hierarchical model arrays cognitive abilities from the most general (Stratum III) to relatively narrow (Stratum I) based on his massive reanalysis of prior factor analytic studies.

Psychometric *g* sits alone at the apex, Stratum III, of Carroll's (1993, p. 627) empirically derived model. In Stratum II are arrayed eight factors that are less general but still quite broad in scope, including General Memory and Learning, Broad Visual Perception, and Processing Speed. In Stratum I are many specific abilities of relatively narrow scope, such as Reading Decoding, Free Recall Memory, and Ideational Fluency. This pattern of overlap or relatedness of distinct abilities, from broad to narrow, can be said to represent "intelligence" (cf. Carroll, 1993, p. 627). When referring specifically to the general factor atop the hierarchy, many of us refer to *g* as "general intelligence."

The broad abilities in Stratum II reflect patterns of covariation among the many specific abilities populating Stratum I. The pattern is that Stratum I abilities correlate more strongly when in the same content domain (verbal, quantitative, spatial, etc.).This indicates that the tests in a cluster measure something in common, in addition to *g*, which is content related (domain specific). When factor analyzed, they yield the broad but domain-specific abilities at Stratum II. These broad abilities also covary, but more tightly than do those at Stratum I. The most general, Stratum III abilities are extracted from the positive manifold (correlations among test results) at Stratum II. Carroll found evidence for only one highly general ability, *g*. He also showed how models that stopped short of extracting a Stratum III *g*, such as Cattell's (1971) model of crystallized and fluid intelligence, could be integrated into his three-stratum model. Carroll determined that fluid *g* and crystallized *g* are Stratum II factors, so Carroll's model is now commonly referred to as the Carroll–Horn–Cattell model.

Fluid *g* is often found to be isomorphic with *g*, and Jensen (1998) considered them to be "one and the same" (p. 106). This makes theoretical sense because both manifest as a domain general capacity for reasoning and solving novel problems. It also accords with Spearman's earlier conceptualization of *g* as a facility for the "eduction of relations and correlates"—in effect, fluid *g*. Crystallized *g* represents broad cultural knowledge and skills (e.g., language) acquired from "investing" fluid *g*. Individual differences in crystallized *g* track changes in fluid *g* until the two trajectories diverge in early middle-age. Crystallized *g* begins to level off, but fluid *g* tends to decline in tandem with the aging of body and brain. As the two trajectories increasingly diverge, crystallized *g* becomes an increasingly misleading indicator of the individual's capacity for learning and reasoning effectively (fluid *g*). For these reasons I conceptualize *g* in terms of fluid *g* when speaking of Stratum III's general factor, *g*.

Kovacs and Conway also report that Stratum III's *g* and Stratum II's fluid *g* "correlate perfectly or almost perfectly" but argue that they "are conceptually different": "Gf represents individual differences in fluid reasoning while *g* does not represent any psychological process" (p. 166). They accept the existence and validity of trait constructs only at Strata I and II in Carroll's hierarchical model. "Therefore, for the stratum (or strata) below *g*, process overlap theory is compatible with a standard oblique model" (p. 161).[1] They then describe why they like Cattell's oblique model, which does not extract a higher order *g*. "A particular appeal of the Gf/Gc model is that the group factors are relatively easy to interpret as within

[1]Presumably oblique models like Thurstone's Primary Abilities and Cattell's Gf-Gc theory.

individual abilities [i.e., processes], which can account for correlations at lower levels of the hierarchy. For example, Gf is interpreted as fluid reasoning, a thoroughly studied cognitive ability, the neural correlates of which are also identified" (p. 155). Moreover, "the reason why tests of fluid intelligence are particularly successful at measuring the processes responsible for the across-domain correlations between mental tests is that they are more or less free from particular domains" (p. 166).

Now, group (Stratum II) factors might seem more interpretable on their face because their scope is defined by particular content domains (verbal reasoning, mathematical reasoning, etc.), yet the high *g* loadings of all group factors indicate that they all tap mostly general processes (reasoning) that cross all domains (reasoning with language, reasoning about mathematical operations), hence the tests' positive manifold. To illustrate the greater interpretability of group factors than *g*, they single out fluid *g*, which they interpret as fluid reasoning, that is, reasoning "more or less free from particular [content] domains" (p. 166). This sounds to me just like Stratum III *g*—domain-independent reasoning—which *g* theorists like Jensen and me have concluded is "one and the same" as fluid *g* and which, as the authors report, are "perfectly or almost perfectly correlated" (p. 166). Another similarity is that tests of fluid *g* produce the same type of scores as does any *g* factor derived from a battery of tests: They reflect only between-individual differences in cognitive ability, not "within-individual processes" (cf. Jensen, as quoted approvingly by the authors on p. 153). The authors nonetheless reject *g* but accept fluid *g* as a valid psychological construct.

Contrasting Understandings of *g* Theory

In fact, Kovacs and Conway reject *g* theory's most foundational conclusions, namely, that Stratum III *g* is a trait (a real dimension of individual differences), that it is a unitary trait (neither an amalgam of disparate abilities nor a "single" process; pp. 158 on evidence that "fractionates" *g*), and that it generates (causes) individual differences in performance on cognitive tests intended to tap more specific abilities (verbal ability, mathematical reasoning, spatial rotation, short-term memory, working memory, processing speed, etc.).

g theory refers to intelligence research in the Galtonian tradition. It was distinctive (and controversial) throughout the 20th century for positing that intelligence has a biological basis and that a general intelligence factor dominates in the pantheon of mental abilities. The tradition is also distinctive for its leaders' sophistication in conceptualizing and measuring human traits, as well as their acumen in formulating and testing hypotheses. Eysenck (1979), for instance, was well versed in both psychometrics and the philosophy of science, and Jensen (1998) was especially adept at making novel predictions and designing incisive experiments that could falsify a favored hypothesis, his or others'.

Kovacs and Conway correctly associate *g* theory with its key developers—Spearman, Eysenck, and Jensen. But *g* theorists would be puzzled by their characterization of *g* theory and its pioneers. For example, the authors argue the superior merits of their theory over *g* theory by sometimes disputing claims attributed to *g* theory that *g* theorists themselves reject. For instance, Kovacs and Conway protest that "There is no psychological process that corresponds to psychometric *g*" (p. 171) and "it appears as if there is simply no place in the brain for general intelligence" (p. 187). But no *g* theorist has ever made that claim, to my knowledge. Even Spearman (1927, Chaps. 15, 16) spoke of multiple cognitive processes involved in *g*, including attention, memory, and mental span. Cognitive psychologist Hunt (2011, pp. 176, 190) concisely echoed the *g* theorists' stance when he wrote that "The brain functions as a system…. There is no single hot spot in the brain associated with all aspects of cognition."

At other times the authors propose views that *g* theorists are said to reject but have actually promulgated for decades. For instance, Kovacs and Conway's process overlap theory "proposes that *g* is characterized as an emergent property, a result of how processes overlap to produce cognitive activity required by mental tests" (p. 171). Yet, far from rejecting this view, Eysenck (1998) argued that *g* is an emergent property of a highly complex system:

> The brain acts like a unit, but this unit is made up of 10 billion cells, interacting in complex ways through numerous structures, hormones, neurotransmitters, neurological structures and physiology mechanisms; supplied with glucose, oxygen and other necessary foods that provide the energy to keep the engine going. … What the IQ really measures is the total effectiveness of the brain. (p. 79)

Jensen likewise referred to *g* as a property of the brain, not an ability per se.

The Seeming Contradictions Explained

How can this be, that the authors and the *g* theorists whom they dispute actually agree on the very issues that Kovacs and Conway say most distinguish them? To explain, I first provide an overview of the full nomological network for *g*, which ranges across the seven levels of analysis sketched in Figure 2. I use it to illustrate how confusion can arise from conflating constructs and evidence at different levels of analysis, in this case (a) test takers' behavioral responses to cognitive tests (Intelligence), and (b) the cognitive processing system by which their brains manipulate information to generate a response (Brain). Figure 2 also highlights the central importance of the external stimuli that activate the cognitive abilities and processes we wish to observe, in particular the complexity of the tasks to be performed. Knowing the overall complexity of tasks also allows us to predict *g*'s gradients of effect in everyday settings.

Different Levels of Analysis in Explaining Intelligence

Any theory of intelligence has to take account of replicated findings at all levels of analysis. Figure 2 depicts the major seven levels for *g*, ranging from the most molecular (genes) to most macro (evolution). Psychometric *g* ("Intelligence" in Figure 2) sits at the junction of the biological and social manifestations of *g*. Jensen referred to these, respectively, as the vertical and horizontal aspects of *g*.

Kovacs and Conway (this issue) integrate evidence primarily at two of the seven levels of analysis: people's brains (Brain in Figure 2) and their responses to cognitive tests and tasks (Intelligence). Their aim is to explain the positive manifold among test scores and hence *g* at the latter level of analysis (Intelligence). They do so by providing evidence of process overlap at

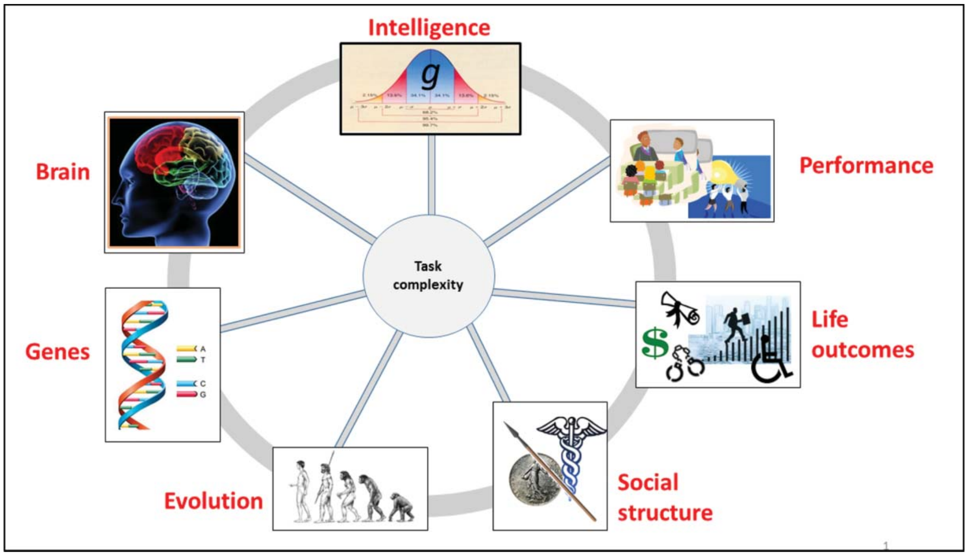

Figure 2. Networks of evidence on *g* spanning different levels of analysis, 2016. *Source:* Figure 4 in Gottfredson (in press). © Elsevier. Reproduced by permission of Elsevier. Permission to reuse must be obtained from the rightsholder.

both levels of analysis. Tests of working memory and other major constructs in cognitive psychology do not measure brain processes directly but provide psychometric "analogs" of them (Hunt, 2011). The authors provide considerable evidence of "process overlap" at this level of analysis (Intelligence). They also call upon research at the Brain level of analysis to support their process overlap theory, including imaging studies of neural networks responding to particular experimental tasks.

Considering evidence at different levels of analysis, as they do, is essential in building theory and testing hypotheses, but levels of analyses must be distinguished, which they do not. A theory is strengthened when data and conclusions are consistent and mesh across levels of analysis, but theoretical coherence does not entail identical conclusions at the different levels. For instance, *g* need not be unitary in the brain if it is unitary at the psychometric level. This, however, is what the authors imply when they criticize unspecified *g* theorists for concluding that *g* exists as a unitary process in the brain, presumably because *g* theorists claim that *g* is *psychometrically* unitary. Only by conflating the two levels of analysis can the *g* theorists' claim that *g* is unitary at the psychometric level be taken simultaneously as a claim that *g* is a unitary process in the brain as well.

Conflating levels of analysis creates a related confusion. It concerns the authors' discussion of whether *g* is a cause rather than an emergent result of the overlap observed among tests and processes in the brain. As Kovacs and Conway repeatedly and correctly stress, psychometric *g* is an emergent property of interacting brain systems, so *g* is their singular *result. g* theorists agree, of course, but the authors attribute the opposite belief to them: that *g causes* the overlap in brain processes. As described earlier, *g* theorists believe that psychometric *g* is an emergent property of the brain but also that, as the brain's unitary product, *g* generates a cascade of effects in the real world.

Ambiguities in the following passage illustrate how the confusion arises. I illustrate the authors' inadvertent conflation of two levels of analysis in the following statement by adding bracketed text to distinguish the two levels, tests and physical brains.

> The most important difference, then, from *g*-oriented accounts of the positive manifold is that whereas reflective general factor theories propose a causal influence of a latent variable, *g*, on the positive manifold [among psychometric tests and life outcomes], according to process overlap theory *the positive manifold [among tests] is an emergent property [of the brain]*, the result of the specific patterns in which item response processes [i.e., information processing systems in the brain] overlap. (p. 162)

With these insertions, the "important difference" disappears. An emergent *g* produced by the brain can, in fact, cause the positive correlations among responses to psychometric tests and experimental tasks in information processing. These patterns of overlap in scores can then be used, in bootstrap fashion, to infer how the brain does and does not go about its work (e.g., working memory) in a way that produces a unitary *g*, which, in turn, produces its own cascade of effects as people go about their lives.

The authors rightly conclude that *g* is not a unitary or single process in the brain. Imaging research has demonstrated that the processes and structures associated with higher intelligence are widely distributed across the brain, whereas verbal and other broad abilities call upon particular brain modules as well. Domain-general processes are concentrated in the prefrontal lobes (e.g., executive function), as would be expected given their remarkable expansion during human evolution. At the Gene level, molecular genetic research is finding that intelligence is radically polygenic and that individual alleles, or single nucleotide polymorphisms, account for only minuscule proportions of variance in intelligence.

In contrast, decades of research in psychometrics, personnel selection, and other behavioral sciences have established that *g* is a psychometrically unitary (indivisible) dimension of human competence. It is unitary at the level of test behavior (Intelligence) and in life outcomes, which are increasingly global and cumulative at higher levels of analysis: Performance in school and work, Life Outcomes like level of education, occupation, and income, and Social Structures such as education, employment practices, and the occupational hierarchy. Psychometric *g* is indivisible, not "fractionated," at these levels because the brain (and person) responds as a unit, whether answering items on a test or calculating the tip for a meal in real life.

More important, evidence converges from various disciplines at these higher, "horizontal" levels of analysis to show that *g* is an especially powerful force in human affairs, shaping even culture itself, precisely because it is a unitary, domain general capacity for learning, reasoning, and problem solving in any life domain (for overviews, see Gottfredson, 1986, 1997b, 2011, in press; Lubinski, 2004). For instance, when broad batteries of ability and personality tests are used to predict individual differences in performance in school and work or in health and socioeconomic success, *g* always "carries the freight of prediction." Stratum II abilities add little or nothing beyond *g* to predicting who will perform best in school, jobs, guarding their health, avoiding premature death, and more. Moreover, general intelligence tends to be the single best predictor in the behavior scientist's toolkit of variables, including social disadvantage, for predicting the level of education, occupation, and income that adults attain. *g* is hardly the be-all and end-all of human performance, but it has unrivaled power when life presents individuals with the need to learn, connect the dots, and figure things out. No specific ability, personality trait, social advantage, or fund of experience has been identified that can compensate for mental powers too weak to lift a task's cognitive load.

How to Determine What g Is and Is Not

As Figure 2 illustrates, the nomological network for *g* has expanded greatly since Spearman set out to explain his discovery. It now reaches into all realms of human functioning, and thereby guides and constrains our theorizing about what *g* is and is not. Some of this hard-won knowledge is captured in the following description of general intelligence (Gottfredson, 1997b). All descriptors are content-free, domain-general manifestations of information processing that lay people also recognize as "intelligence."

Intelligence is a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings—"catching on," "making sense" of things, or "figuring out" what to do.

Factor analysis does not explain the factors it yields, as Kovacs and Conway note. Nor did Spearman or any other any *g* theorist of the Galtonian tradition believe that it could. Indeed, when Hans Eysenck returned to the topic of intelligence in the late 1960s,[2] he argued (Eysenck, 1979) that factor analysis had nothing more to contribute to understanding *g*. He also complained that psychometrics had become focused on the technology of testing and showed scant interest in the constructs tests actually measures.

As the authors also illustrate, understanding intelligence is a long investigative process, with many iterations in collecting data and revising hypotheses. Intelligence is not "defined" but described by laboriously creating a portrait of the phenomenon as embedded in broader networks of human functioning—a nomological network. *g*'s theoretical meaning is inferred from replicated patterns gleaned from multiple, ever-evolving bodies of evidence.

Eysenck approached intelligence as a biological phenomenon, so his laboratory began noninvasive studies of elemental processes in the brain. He used the only tool available at the time, the EEG, to watch the brain in real time responding to experimental stimuli. He also developed choice reaction time tasks (e.g., the odd-man-out task) that better instantiated Spearman's (1927, p. 410–411) theoretical description of highly *g*-loaded tests as requiring the "eduction of relations and correlates." EEG brain waves and reaction time on exceedingly simple tasks (e.g., touch a button when it lights up) were as close to the brain as he could get.

Arthur Jensen, another pioneer in understanding *g*, wrote often about the "g beyond factor analysis." His review (Jensen, 1998) of the many biological and sociological correlates of *g* helped demonstrate that *g* was no chimera of factor analysis, Gould (1981) notwithstanding. It was especially important to Jensen to determine whether *g* was a replicable phenomenon across human populations. He and others therefore investigated whether different populations and different test batteries produce different *g* factors, or whether they all converge on the same "true" *g*. Prominent psychologists such as Anne Anastasi (1970, 1983) had been arguing that different cultures create different abilities and, later, would argue that the *g* dimension of correlated individual differences is a product of Western education. However, all derived *g*s turned out to converge on the same "true" *g*, surely a biological fact in itself.

Kovacs and Conway (this issue) argue that "*g* is far from being a constant" (p. 155), but they mean something different. For them, it means that *g* (the positive manifold) does not account for the same proportion of variance in a test battery's scores in all groups of people or batteries of tests, though admittedly the lion's share in all. It is theoretically intriguing that *g* accounts for a smaller proportion of test score variance among high-*g* than low-*g* individuals, but the construct validity of a domain-general human capacity does not rest on its being equally dominant among cognitive abilities in all circumstances and populations.

The positive manifold that is *g* is similar in this respect to the heritability of intelligence, which is just the proportion of phenotypic variation in a population that can be attributed to genetic variation. The proportion of total variance accounted for by the "general factor" in question (genetic variation, variation in *g*) can differ depending on age, statistical artifacts (e.g., measurement unreliability, restriction in range in test scores), and conditions that allow versus block individuals from expressing their potentials and proclivities (e.g., relaxed vs. rigid rules for behavior; tests that are not too hard or too easy vs. those that are). Not being "constant" in this narrow sense does not contradict the universality of the *g* dimension in human populations. The validity of *g* as a human universal rests instead on whether the *g*s derived from different populations and test batteries exhibit the same properties, such as showing the same pattern of relations with other variables after correction for statistical artifacts. Stated another way, what matters is evidence that cognitive differences in all populations align

[2] Eysenck's (1939) first publication reconciled Spearman and Thurstone's dueling factor analytic models: Spearman posting only a general factor (*g*) and test specificity, and Thurstone positing a set of distinct primary abilities but no general factor.

themselves in the same relation to one another along the same underlying continuum, or "true" *g*.[3]

Kovacs and Conway draw on various sorts of evidence, including their own, to conclude that psychometric *g* is an emergent property of the brain and to rule out notions of it being a single process or place in the brain. So did Eysenck and Jensen. As noted earlier, Eysenck argued that the brain acts as a unit but its internal workings are exceedingly complex. He started his inquiries into the brain by focusing on speed of processing (e.g., latencies of particular brain waves in response to a sound) but soon concluded that speed of processing involved more than mere conduction speed. He and his research team speculated that physiological properties such as myelination of axons in the brain's white matter might explain differences in efficiency or error rates in neural transmission, which would also slow speed of processing. In his last book, Eysenck (1998) discussed the nascent body of research on brain-wide efficiency in information processing, including the first imaging study of normal intelligence (Haier et al., 1988), which found that brighter brains use less glucose when solving problems. He anticipated, but sadly did not live to see, the enormous advances in tracing neural networks that Kovacs and Conway (this issue) mention.

Jensen[4] (2006) was particularly interested in reaction time studies as a window into the brain, not because he thought speed alone explained intelligence but because units of time (e.g., milliseconds) provide ratio-level measurement of mental processes. Standard cognitive tests do not. He considered norm-referenced test scores (performance relative to some reference group's mean) a major barrier to progress in understanding general intelligence. I should note that norm-referenced measurement is far less a problem for understanding *g*'s causal effects at the horizontal levels of analysis in intelligence. The reason is that social life operates as a comparative, competitive system of (being the more qualified job applicant, "getting ahead"), as does evolution itself.

How Variations in Task Complexity Help Expose What g Is and Does

Figure 2 places task complexity at the hub of all seven levels of *g*-related phenomena. In my view, it is the key to explaining *g*, from how it evolved to how it operates in the real world. Why? Because cognitive abilities and processes manifest themselves, become observable, and exert their causal power only when activated by some stimulus. In fact, abilities are named and classified by the range of tasks on which they enhance performance.

> As used to describe an attribute of individuals, *ability* refers to the possible variation over individuals in the … levels of task difficulty … at which, on any given occasion in which all conditions appear favorable, individuals perform successfully on a defined class of tasks. (Carroll, 1993, p. 9)

The question, then, is what features of a task or stimulus evoke domain general processes and *only* domain general processes, ones not limited in scope by any content boundaries, which in turn generate the positive manifold among tests? The literatures in many domains of human performance, from ergonomics and academics to health and occupational advancement, point to how the cognitive complexity of work performed drives the magnitude of individual differences and effect sizes in performance (e.g., variances, correlations, mean differences). As sociologists documented in the 1970s, even the worldwide occupational prestige hierarchy orders occupations by overall complexity and thus cognitive demands and average IQ of incumbents. These literatures discuss task complexity at different levels of granularity: For example, a functional literacy item might require the individual to use two rather than one bit of information, and a job might routinely require workers to analyze information rather than just code it.

Psychometric tests are carefully contrived stimuli for evoking information-processing behavior at increasing levels of difficulty. Spearman and Jensen both sought to understand what made some items and tests more difficult and zeroed in on how complexity increases item difficulty, for instance, abstractness of the information to be processed. So have the developers of the U.S. Department of Education's adult literacy tests. They (Kirsch, Jungblut, Jenkins, & Kolstad, 2002) traced item difficulty on all their scales (Prose, Quantitative, Document) to the same "processing complexity": principally, abstractness of information, amount of information, and distracting information (the third requiring cognitive "inhibition" as described by Kovacs and Conway). Daily life is suffused with such cognitive complexity. The more novel and complicated a task, the more *g* loaded it will be. Patterns in the complexity (*g* loading) of tests and life tasks allow one to predict *g*'s gradients of effect in any performance domain or life arena because they are so regular.

I was therefore delighted to see Kovacs and Conway (this issue) describe how experimental tasks in cognitive psychology that are more complex show larger effect sizes. Indeed, the authors highlight complexity as one of four important features of the positive manifold among tests that their theory explains (p. 155): "more complex tests load higher on *g* than less complex tests (Jensen, 1981)." They provide numerous examples when discussing research on working memory (pp. 156–158), which they repeatedly illustrate throughout their article. "Of course, the characteristics of the task determine the nature of the processes involved at arriving at a correct solution" (p. 164).

Yet they argue that this feature is theoretically uninformative: "However, 'complexity' is not an explanatory concept that can help our understanding of *g*" (p. 155). Their reasons are that experts do not agree about (a) "how complex a test is" or (b) "how complexity differs from difficulty (Mackintosh, 1998)" and because (c) "there are certainly different 'complexities' … that probably invoke rather different cognitive processes" (pp. 155). They suggest that understanding the *g*-complexity relation requires first understanding "the cognitive processes involved in more 'complex' tests" (p. 156). However, it would seem more useful to reverse the order and

[3] Jensen always cautioned that precision in measurement and conceptualization was essential for theoretical purposes. Degree of error must be taken into account to avoid misinterpreting research results, for example, by not realizing that mean differences or correlations have been artificially lowered by common statistical artifacts.

[4] Jensen began his career as what we would now call a cognitive psychologist, for instance, conducting experiments with the Stroop test to understand general principles in learning.

use the elements of a task's complexity to identify the processes they call forth.

If I understand their argument correctly,[5] their first and second rationales for rejecting a theoretical link between *g* and complexity—experts cannot agree on what complexity is or how it differs from difficulty—would (if valid) seem to apply to process overlap theory as well. However, consensus is not a criterion for demonstrating validity or utility, and Jensen (1998, p. 94) explained the difference between a test's complexity (*g* loading) and its difficulty (% passing), as well as how tasks can be difficult without being complex (memorize 100 telephone numbers in 10 min). Complexity is an attribute of cognitive tasks and refers to differences in the cognitive load they impose for successful performance (e.g., bits of information to integrate, inferences required, abstractness of concepts, irrelevancies to ignore). In contrast, difficulty refers to the proportion of test items that are failed in a specified population, meaning difficulty depends not only on the intensity of the test's cognitive demands but also on the ability level of the individuals tested. Less able populations pass fewer items, so the same test earns a higher difficulty rating when administered to lower-*g* than higher-*g* populations. Complexity is an attribute of tests that can be ascertained independent of whoever might take them, if anyone. In contrast, a test's difficulty and its *g*-loading are population dependent because they derive from the scores of people who took the test.

Their third reason ("there are certainly different complexities") is more to the point, but precisely because understanding what makes tasks more versus less cognitively complex is absolutely crucial for understanding the nature, origins, and consequences of human variation in a capacity that transcends the particulars of time, place, form, and content of information. If we better understood the various task attributes that call for additional sorts of information processing, we might be in a better position to understand the nature, number, and relations among the processes themselves.

Kovacs and Conway are correct that there is no consensus on the meaning of complexity, at any level of analysis, despite researchers' frequent appeal to the concept. However, the authors are ideally qualified to resolve that matter. As they say, "Of course, the characteristics of the task determine the nature of the processes involved at arriving at a correct solution" (p. 164). It would be an enormous contribution, both to research and theory on intelligence, for them to spell this out. I have searched in vain for a system that allows one to systematically identify and catalog the elements of a cognitive task that ratchet up its complexity. Such a system would have practical applications as well: for example, to chart and reduce the heavy cognitive demands in health self-care today that generate high rates of patient error and nonadherence to treatment, which mightily frustrate health care providers and endanger patients. When critical self-care tasks are too difficult for patients, the tasks can be restructured but patients' brains cannot.

[5] I cannot be sure because Kovacs and Conway (this issue) refer to complexity sometimes as an attribute of cognitive processes ("This implies that g is related to the complexity of cognitive activity," p. 155), sometimes as an attribute of experimental tasks that evoke them ("how complex a test is," p. 155), and at other times as the extent to which one particular class of processes is used in solving problems ("the overlap is caused by executive functions," p. 171).

How Task Complexity Links Experimental and Differential Research on Intelligence (Within- vs. Between-Individual Differences)

Systematic attention to the elements of task complexity would have another important benefit, namely, directly joining the experimental and differential approaches to intelligence. The authors refer to them, respectively, as the within-individual versus between-individual approaches because that is the partition of variance in mental performance that each tries to explain. Cronbach (1957) referred to them as the "two worlds of scientific psychology" because it was as if they inhabited different planets. Even today, they still speak different dialects, pursue different goals using different methods, convene separately, publish in different journals, and trace different lineages. It is no surprise that they sometimes misunderstand one another. I describe one such misunderstanding reflected in the authors' article so that I can better explain the second way they could exploit task complexity to great benefit.

Kovacs and Conway (this issue) offer a "critique of the interpretation of *g* as a within-individual construct" (p. 153). Their concern is that "the concept of general intelligence interprets *g* as a within-individual mental ability" (p. 153). Their concern is misplaced, however, if by "concept of general intelligence … interprets" they mean *g* theory, and if by "within-individual mental ability" they are referring to how brains typically process information rather than how some brains work better than others. They themselves (p. 153) quote Jensen (although to support a different point) clarifying how studies of individual differences in intelligence do not capture thought processes measurable only by studying what goes on within the minds of individuals. Once again, the apparent contradiction between process overlap theory and *g* theory dissolves into agreement.

All traits are by definition accounts of differences between people, and virtually all if not all measures of psychological traits report scores on a norm-referenced scale (distance from the average) such as IQ, z, T, and stanine scores, rather than on an absolute scale such as minutes, inches, pounds. Intelligence, extraversion, neuroticism, self-esteem, and such refer to continua along which individuals differ, but ones not anchored to any meaningful zero point (total absence). We scientists foster confusion among nonscientists by not prefacing trait names with "differences in" because nonscientists often wrongly assume we are referring to absolute measures like height and weight (e.g., "Casey is 40% smarter than Meredith"). That shorthand for traits is why *g* is sometimes mistaken as "a within-individual construct," to which Kovacs and Conway rightly object.

Although not directly illuminating how brains process information, differential studies are nonetheless valuable for generating and testing hypotheses about how they do so. Haier et al.'s finding of differential glucose uptake by intelligence level is an early example. A decade earlier, in 1973, cognitive psychologist Earl Hunt and his colleagues (Hunt, 2011, p. 143) published a series of studies on the information-processing correlates of verbal and mathematical reasoning. It stimulated a "blizzard" of such studies. As Kovacs and Conway's review of evidence illustrates, cognitive psychologists today often turn to differential studies to further their experimental work on information-processing constructs, such as working memory and executive function. In like manner, brain imaging neuroscientists are supplementing their correlational studies of intelligence and brain action with experimental studies.

Both the experimental ("within") and differential ("between") approaches require the administration of cognitive tasks, and they often use the same or similar ones. Both approaches have discovered that domain processes ("within") and general abilities ("between") are activated by the domain-general demands of a task, referred to generically as its "complexity" as distinct from its content. The key difference is that first approach would compare two tasks performed by the same individual, whereas the second would compare two individuals performing the same task (within vs. between individuals variation). Either approach can provide clues for the other—how do minds operate, and how do minds differ?

Being able to characterize tasks according the attributes generating their complexity, and by how much, would provide a common metric for integrating results from the two types of research. For instance, if both administered three timed tasks of increasing complexity, an experimental study would look at how given increases in task complexity (ΔX) change individuals' successive responses (ΔY), perhaps by slowing them down as more cognitive processes are recruited to answer the more complex task correctly. A differentialist study would look at how much the same increments in task complexity (ΔX) expand the differences in how quickly individuals respond ($\Delta\sigma_y^2$) and tighten the correlation (Δr_{xy}) between response times and intelligence level. A metric for task complexity would also allow placing findings from both approaches into a common, quantitative frame of reference. In effect, to reunite the two partitions of variance.

Conclusion

Kovacs and Conway have provided a critique of *g* theory to justify proposing a new theory, process overlap, for explaining an old but still remarkable discovery about human intelligence. I have explained various ways in which their critique is misplaced. But my main point is that the critique was unnecessary. Not because the two theories actually align, not collide, but because the authors' illumination of how cognitive processes themselves align stands on its own. They need no theory to fall for theirs to stand. More than that, I believe they could make major contributions in understanding how the confluence of domain-general reasoning processes is evoked by external demands and opportunities to solve problems effectively and efficiently. To that end, I encourage them to parse the complexity of the stimuli that instigate cognitive action. Success in quantifying the cognitive load of different experimental tasks would also help bridge the "two worlds" of intelligence research.

Acknowledgments

This article is dedicated to the memory of Earl B. Hunt (1933–2016): Friend, colleague, constructive critic, and leader in joining psychology's experimental and differential approaches to intelligence.

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