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What Is IQ? Life Beyond "General Intelligence"

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Abstract
For more than a century, the standard view in the field of human intelligence has been that there is a "general intelligence" that permeates all human cognitive activity. This general cognitive ability is supposed to explain the positive manifold, the finding that intelligence tests with different content all correlate. Yet there is a lack of consensus regarding the psychological or neural basis of such an ability. A recent account, process-overlap theory, explains the positive manifold without proposing general intelligence. As a consequence of the theory, IQ is redefined as an emergent formative construct rather than a reflective latent trait. This implies that IQ should be interpreted as an index of specific cognitive abilities rather than the reflection of an underlying general cognitive ability.

Keywords
IQ, intelligence, process-overlap theory

Intelligence tests are available in various forms; many different and seemingly unrelated tests appear under this umbrella term. Some require reasoning about abstract figures. In others, one must memorize digits, find synonyms for words, compose figures from pieces, or find certain shapes in a visual array as quickly as possible. Individuals who perform well on practically any of these tests are likely to perform well on the rest, too. This empirical result is known as the *positive manifold*, which refers to the pattern of all-positive correlations among different tests of intelligence.

The positive manifold is a robust finding, but its strength is not universal: Correlations between different tests are lower in people with higher overall ability (Blum & Holling, 2017; Molenaar, Kő, Rózsa, & Mészáros, 2017). This finding, called *ability differentiation*, means that the positive manifold is stronger below the mean IQ and weaker at the highest levels of IQ. As a result, cognitive ability appears to be more general below the mean IQ and quite specific at high IQ.

Following Spearman's (1904) pioneering work, most researchers explain the positive manifold by a general factor, *g*. Spearman's original explanation proposed that all IQ tests measure a single general factor plus test-specific variance. The idea that all IQ test scores reflect a single general factor has been crucial in establishing the construct *general intelligence*, or *general cognitive ability*, which plays a role in any intelligent activity and that all different IQ tests measure.

Studies conducted since Spearman's (1904) have revealed that there are also clusters of tests in which correlations are stronger within clusters than across clusters. For instance, vocabulary and reading comprehension correlate more strongly with one another than with mental rotation. In factor analysis, this results in broad—but still specific—group factors such as verbal and visuospatial ability. The correlations between these group factors are, in turn, explained by the now "higher-order" general factor, *g*.

However, the term *explained* can be interpreted in both a statistical sense and a psychological sense. Statistically, *g* indeed explains much of the positive manifold, which means that the correlations between tests (or broad abilities) can be accounted for with the tests' (or abilities') correlation with *g* as a latent variable. Yet a psychological explanation would mean pointing to actual processes and mechanisms represented by *g*. Without that, *g* remains a statistical construct: It summarizes the common variance among the tests or lower-order factors.

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This results in an illusion of explanation: Positing a general factor gives the false impression that there is a psychological explanation, whereas the actual explanation is purely statistical.

Importantly, since the general factor is a necessary mathematical consequence of the positive manifold (Krijnen, 2004), in a statistical sense, *g* is essentially a more sophisticated way of restating that IQ tests with diverse content correlate positively. It is not *g* as a statistical construct, but *g* theory—the idea that *g* represents a psychological attribute—that is controversial.

According to *g* theory,

> *g* may be thought of as a distillate of the common source of individual differences in all mental tests, completely stripped of their distinctive features of information content, skill, strategy, and the like. . . . At the level of causality, *g* is perhaps best regarded as a source of variance in performance. (Jensen, 1998, p. 74)

Thus, *g* theory is a sufficient but not necessary explanation of the positive manifold.

Unfortunately, an adequate psychological understanding of the source of *g* is still missing (for a review, see Chapter 5 of Mackintosh, 2011). In fairness to proponents of *g* theory, there have been several candidates proposed as the source of a unitary construct affecting all kinds of intellectual activity. At the same time, the idea of "psychological *g*" is also contradicted by a number of findings from neuropsychology and cognitive science. The aim of this article is not to do justice to or even review evidence for and against psychological *g*. There are several summaries of *g* theory; we direct the interested reader to one of those, the book, *The* g *Factor* (Jensen, 1998). In this article, we offer an alternative approach to understanding human intelligence and IQ.

Process-Overlap Theory (POT)

Besides the positive manifold and ability differentiation, there are other important findings to consider regarding human intelligence. One is related to fluid reasoning (Gf): the ability to solve problems in novel situations in which one cannot rely on already-acquired skills or knowledge (Cattell, 1971; Horn, 1994). Gf is typically measured with nonverbal inductive-reasoning tests and has a central role in the structure of intelligence. That is, if we would like to predict someone's score on one broad ability from another, predictions based on Gf will be most accurate. Relatedly, *g* and Gf are nearly indistinguishable in a statistical sense (Gustafsson, 1984; Kan, Kievit, Dolan, & van der Maas, 2011).

Another important finding in intelligence research is that the more complex a task, the higher it correlates with *g*. For instance, backward digit span, in which participants must recall digits in reverse order, correlates more strongly with *g* than simple digit span. Yet another important phenomenon is the *worst-performance rule*: The worst performance on cognitive tasks is a better predictor of *g* than the best performance (Rammsayer & Troche, 2016).

Taken together with ability differentiation, the worst-performance rule reveals that *g* is most prevalent at low levels of ability and is best predicted by weak performance. It appears that there is a central system that limits performance. We recently provided an explanation of these various findings that indeed focuses on limitations in cognitive performance. That is, it is aimed at explaining why people do *not* solve items on mental tests and why this results in the positive manifold.

This explanation, called *process-overlap theory* (POT), does not propose a general cognitive ability and therefore does not endorse psychological *g*. Instead, it proposes that intelligence is determined by multiple components, both domain-general and domain-specific. Certain domain-general processes (often called *executive functions* in the literature, e.g., Diamond, 2012) overlap with domain-specific processes during mental test performance. These executive processes are central to human intelligence in the sense that they are tapped by a large number of tests. Specific processes, on the other hand, are mostly tapped by tests with corresponding specific (verbal, spatial, etc.) content only.

Executive processes thus function as a bottleneck: They constrain performance in a wide variety of tests that tap different domains. Hence, performance in these different, specific domains (verbal, spatial, etc.) correlate, and the positive manifold emerges. Moreover, the lower the level of executive functions, the stronger the bottleneck effect and the higher the correlations between diverse tests: This, according to POT, is the explanation of ability differentiation.

POT is inspired by research on working memory, the cognitive system for maintaining goal-relevant information in the face of concurrent processing or distraction. Measures of working memory capacity (WMC) typically demand parallel storage and processing. For instance, whereas word span, a test of short-term memory (STM), requires one to simply memorize words, reading span, a test of WMC, requires one to read sentences and remember their last words. The additional processing component matters; WMC is a better predictor of intelligence and academic achievement than STM. WMC is also more domain general than STM: Verbal and spatial WMC correlate more strongly than verbal and spatial STM (Kane et al., 2004). Also, WMC is strongly related to Gf, and the two constructs share a majority of their neural correlates (Kane, 2005).

Several latent-variable studies have disentangled the unique variance in WMC from the variance it shares with measures of STM and found that the WMC–Gf correlation is driven by whatever working memory tests measure beyond storage and retrieval (Conway, Kane, & Engle, 2003; Engle, Tuholski, Laughlin, & Conway, 1999). To take reading span as an example, these are the processes that we engage when we remember a list of words presented at the ends of sentences but that we do not engage when we simply remember a list of words. These processes are called *executive*, responsible for so-called cognitive control and the organization of complex cognitive activity (Engle, 2002; Gratton, Cooper, Fabiani, Carter, & Karayanidis, 2018). As defined by Diamond (2012), executive functions "refer to a family of top-down mental processes needed when you have to concentrate and pay attention, when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible" (p. 136).

The difference between measures of WMC and measures of STM is that the former tax executive processes more, while not putting any less demand on storage and retrieval. According to POT, this is the reason why *g* and Gf correlate more strongly with WMC than with STM and with more complex tasks in general.

Eyeballing the content of most IQ tests, it may not be obvious why executive processes are relevant for performance. Yet they are responsible for the basic requirement of staying focused on the test:

> Domain-general attention control allows test takers to stay focused on the tasks during delay periods and provides a mechanism to protect information from interference. This mechanism appears to be a common component of all valid tests of working memory capacity (regardless of domain). (Shipstead & Yonehiro, 2016, p. 1510)

To be clear, highly efficient executive processes will not guarantee success on cognitive tasks, including tests of intelligence. But inefficient executive processes make failure more likely, regardless of the domain-specific content of a given test. As research on *goal neglect* demonstrates, people with low Gf struggle to stay focused on a task in the same way that patients with damage to prefrontal cortex do (Duncan et al., 2008). According to POT, this is why WMC is more domain general than STM: Performance on both spatial and verbal WMC tasks is likely to be more limited by executive processes than in spatial and verbal STM tasks.

This executive bottleneck, represented in a formal mathematical model, is the primary proposal of POT (Kovacs & Conway, 2016). Besides the positive manifold itself, it also explains ability differentiation and the worst-performance rule. People who generally perform below average on cognitive tasks (low ability) are likely to exhibit deficits in executive processes that impact performance across a range of domains. In contrast, people who generally perform above average on cognitive tasks (high ability) are unlikely to exhibit deficits in executive processes, so their performance primarily reflects domain-specific processes. That is, the lower the level of executive functions, the stronger the bottleneck effect and the higher the correlations between diverse tests: This, according to POT, is the explanation of ability differentiation.

Similarly, since poor performance is indicative of attentional deficits, it is strongly related to *g*. Finally, according to POT, the reason that Gf has a central role in the structure of abilities is that it is more strongly related to WMC and executive processes than any other broad ability.

It cannot be overemphasized that POT does not equate *g* with some central executive. First, WMC is a multiply determined construct (Conway, Getz, Macnamara, & Engel de Abreu, 2011), and executive functioning is not unitary either. There appears to be "a cluster of largely autonomous control processes—an executive committee" rather than "a single coordinated system that serves multiple functions, a true executive" (Baddeley, 1996, p. 26). Second, POT claims that executive processes are tapped by a larger number of tests than specific processes, but there is no need for a single process to be involved in all cognitive activity for the positive manifold to emerge.

POT has its historical antecedent in Thomson's *sampling model* (Bartholomew, Deary, & Lawn, 2009; Thomson, 1916), which proposes that some processes are "sampled" by IQ tests more often than others and that the correlation between any two tests is the direct function of the number of overlapping processes. While acknowledging the influence that sampling theory has had on POT, we point out that there are crucial differences that in part stem from advances in the understanding of the mind and the brain since the time of Thomson's theorizing. First, the sampling model does not specify processes, whereas POT points to executive functions as the most frequently sampled processes. Second, in the sampling model, process scores are added to determine an overall outcome, while POT proposes a bottleneck effect and thus nonlinearity, which is expressed in the mathematical model (Kovacs & Conway, 2016).

Besides explaining key findings in intelligence, POT also makes novel predictions. A central prediction is that ability differentiation exists in WMC and is stronger in WMC than in STM. These predictions have been supported (Kovacs, Molenaar, & Conway, 2019). Another prediction is that a standard factor model with a strong general factor will fit psychometric data, even if the data are simulated so that they meet the proposition of POT; that is, without a single unitary system being involved in all tests. Indeed, a simulation study confirmed this prediction (Kan, van der Maas, & Kievit, 2016).

As in the case of any new theory, POT also faces challenges and limitations. A more fine-grained understanding of the nature of the executive processes that are currently defined in global terms—as the ones responsible for the management of complex goal-directed behavior such as cognitive control or executive attention—will improve the explanatory power of POT. In particular, the involvement of such processes in cognitive test performance needs to be further explored. This will probably be achieved by research on the neural underpinnings of such performance, as well as by a network approach to the analysis of psychometric data.

What Is IQ?

According to POT, *g* is an emergent property rather than a causal latent trait: It is the consequence, not the cause, of correlations between cognitive ability tests or—more typically—between specific cognitive abilities. Latent variable models are called *reflective* if a latent trait is reflected by measures: Most models of intelligence belong to this kind. Yet such models are only compatible with a so-called realist ontology (Borsboom, Mellenbergh, & van Heerden, 2003): If tests reflect *g*, then *g* must represent something "out there" that exists without measurement. POT is opposed to reflective *g*, and so is mutualism, a developmental account of the positive manifold that does not entail an underlying causal latent variable either (van der Maas et al., 2006).

Models in which the latent variables are caused by intercorrelated measures or lower-order variables are called *formative*. In such models, the latent variable—or, perhaps more appropriately, the composite variable—would not exist without measurement. A typical example is socioeconomic status, which is the result of a number of correlated social, financial, and educational variables. POT implies a model of intelligence that is formative with respect to *g*.

According to *g* theory, one performs well on mental tests because of one's high *g*. According to POT, this is not any more valid than claiming that one has high income, high social status, and a college degree because of one's high socioeconomic status; the direction of causation is the opposite. A reflective approach is tenable for broad abilities that do have a causal role in performance, but not for *g*. To paraphrase the central notion of *g* theory as defined by Jensen (1998), under the framework of POT, *g* may be thought of as a distillate or the common consequence of individual differences in all mental tests, completely stripped of their distinctive features of information content, skill, strategy, and the like. At the level of causality, *g* is perhaps best regarded as a result of covariance in performance.

Both IQ and *g* are, therefore, index variables of cognitive performance, similar to indices such as the Global Competitiveness Index or the Organisation for Economic Co-operation and Development's Better Life Index, which are simply weighed sum scores. It should be taken seriously that the best definition of intelligence is the thing measured by IQ tests (van der Maas, Kan, & Borsboom, 2014). At the same time, such indices can be appropriate and useful for a number of important practical applications; IQ and *g* are no exceptions.

Are IQ tests completely arbitrary then? Far from it. It has been demonstrated that if IQ test batteries are diverse enough to include a large number of broad abilities, then the general factors extracted from such batteries are identical (Johnson, Bouchard, Krueger, McGue, & Gottesman, 2004). Therefore, a good measure of IQ is a large enough battery that is also able to provide a profile-type assessment that highlights individual strengths and weaknesses. Such a profile is especially more informative than an overall IQ if there is substantial discrepancy between the scores on specific abilities which, because of differentiation, is most probable at the highest levels of ability. Or if for some reason a single measure is sufficient, the best candidate to predict overall IQ is fluid intelligence because of its central role in the structure of abilities and its near identity with *g*.

A formative interpretation of *g* has consequences for both research and practice. The interpretation of IQ as an index of different abilities rather than a reflection of general intelligence has already been discussed. Another practical implication is that formative *g* is primarily for the prediction of important real-life outcomes. This is already an established area of intelligence research, along with research aiming to unravel the genetic and neural basis of *g*. If *g* is formative, then in the search for the neural and genetic basis of human abilities, "the most fruitful path . . . would be to focus on those lower order variables that do allow for a realist, causal interpretation" (Kan et al., 2016, p. 220). Research on human intelligence has been hindered for a long time by "overemphasizing *g*" (to paraphrase Stankov, 2017). We should therefore dismiss the notion of psychological *g* and concentrate our efforts on understanding the cognitive processes and neural mechanisms that give rise to more specific cognitive abilities.

Recommended Reading

Conway, A. R. A., & Kovacs, K. (2015). New and emerging models of human intelligence. *Wiley Interdisciplinary Reviews: Cognitive Science*, *6*, 419–426. A summary and review of models and theories that provide an alternative to *g* theory, including process-overlap theory.

Engle, R. W. (2002). (See References). An accessible summary of the executive approach to working memory capacity.

Kovacs, K., & Conway, A. R. A. (2016). (See References). A slightly technical article that outlines process-overlap theory (followed by 12 commentaries and the authors' response, for the most devoted readers).

Stankov, L. (2017). (See References). An important and comprehensive article reviewing the unfortunate consequences the extensive focus on *g* has had on intelligence research.

van der Maas, H. L. J., Kan, K.-J., & Borsboom, D. (2014). (See References). A highly accessible and entertaining article on a formative approach to intelligence.

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