decline of fluid intelligence" (p. 53). Schretlen et al. found that age-related declines in executive ability and frontal lobe volume accounted for a significant amount of variance in fluid intelligence and revealed a significant negative correlation between fluid intelligence and age. Using various measures of intelligence, we have found converging evidence that indicates that, while crystallized intelligence remains stable, fluid intelligence and executive function performance decline with age, with the most prominent decline beginning in the 60s (Zook et al., in press). In another study looking specifically at older adults, we found that although full-scale intelligence scores in our sample of older adults were above the population mean of 100 and significantly higher than in the younger adult group, the older adults' performance on a fluid intelligence task was significantly below that of the younger adults. Performance on two executive ability tasks, the Tower of London and the Wisconsin Card Sorting Task, were also significantly lower in the older adult group.

These results support Blair's proposal that a neurobiological model is needed that differentiates cognitive processes associated with the PFC from a general, psychometrically defined general intelligence across the life span. It is important to understand the specific developmental aspects of fluid intelligence (e.g., late development and early decline of the PFC) not only as part of a theory of cognitive development, but also in terms of neuropsychological assessment and intervention. Following from the ideas presented by Duncan et al. (1995), Kane and Engle (2002), and our data, we suggest that intelligence batteries such as the WAIS and WISC may not identify specific types of impairments in cognitive functioning associated with fluid intelligence. Blair points out that it is important to study cognitive function and variations in performance by using a neuropsychological and psychometric framework and to look at development in typical as well as atypical populations. It is also suggested here that when studying and assessing cognitive function across the life span, multiple measures of fluid intelligence should be used in addition to more general measures of intelligence. Such an approach could identify functional cognitive differences and allow for the implementation of interventions both developmentally and in late adulthood.

Author's Response

Toward a revised theory of general intelligence: Further examination of fluid cognitive abilities as unique aspects of human cognition

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Abstract: Primary issues raised by the commentaries on the target article relate to (1) the need to differentiate distinct but overlapping aspects of fluid cognition, and (2) the implications that this differentiation may hold for conceptions of general intelligence. In response, I outline several issues facing researchers concerned with differentiation of human cognitive abilities and suggest that a revised and expanded theory of intelligence is needed to accommodate an increasingly diverse and varied empirical base.

R1. Introduction

A number of important issues and challenges are raised by the commentaries on the target article, which need to be addressed. It is worth noting at the outset, however, that most of the commentaries are in agreement with the need to clearly differentiate fluid cognitive abilities from general intelligence. All but one or perhaps two of the commentaries take the position that there is something to be gained by such differentiation, and really none presents an all-out defense of *g*, the general factor of intelligence, in an attempt to discredit the target article's primary thesis. This is of considerable interest and perhaps suggests that reliance on the explanatory power of the mathematically derived general factor in research on human intelligence is appropriately on the wane. Certainly the scientific foundation on which the general factor rests is very clear, and it is without question one of the most enduring constructs in the history of psychological research. However, the individual differences framework for the construct is inherently limited by its correlational nature and, despite its claims to comprehensiveness, has not been able to provide a well-grounded explanation for the aspects of human behavior with which it is associated. Accordingly, I suggest that the general factor in its familiar form is headed for the margins of scientific inquiry because of a fundamental lack of specificity. But whether the construct will go, in the immortal words of T. S. Elliot, "not with a bang but a whimper," or whether Samuel Clemens' "the report of my death was an exaggeration" will prove a more apt characterization of the future of the general factor as an aspect of research on intelligence, is certainly open to question.

Although one could argue endlessly about whether the construct of general intelligence in its familiar form will or will not fade from the scientific limelight, it is my opinion, and I think that of many others, that the decline of the explanatory power of the general factor has been apparent for some time. The relevant question is how to best fit new data and insight into the old order of *g*. This is really the core of scientific change in the sense of Thomas Kuhn (1962). How can we best go about instantiating change in the study of human cognitive abilities within the time-honored framework of *g*? In part, it is the variety of ways in which this may be accomplished that lies at the heart of the issues raised by the commentaries.

In this response, I examine some logical next steps in revising the theory of general intelligence to accommodate an expanded view of fluid cognition. In doing this, I first respond to commentary focusing on theory development and the expansion of the empirical base in research on intelligence. I then turn to what I think are some of the key issues facing researchers concerned with the differentiation of fluid cognitive abilities from general intelligence. Here I examine definitional issues and address concerns regarding the unity versus diversity of executive function (EF), working memory (WM), and fluid intelligence (gF). In response to commentators suggesting the need for greater differentiation of EF, WM, and gF, I outline evidence in support of an integrated fluid cognitive construct. In this, I also examine the role of attention in fluid cognitive functioning and juxtapose the model presented in the target article with John Duncan's adaptive-coding model of gF. I also further examine the role of emotion and the stress response in fluid cognition and conclude by suggesting that research on intelligence can best advance through the examination of associations among psychological and neurobiological variables.

R2. Revising the theory of general intelligence

Interest in the way forward in the study of human cognitive abilities is the specific focus of the commentaries by **Anderson**, **Flynn**, **Ford**, and **Wilke**. The commentary by Flynn, in particular, thoughtfully articulates the need for a revised theory of intelligence. The research base on the study of intelligence now indicates that the current individual-differences frame must be expanded to accord equal weight to neurobiological and sociological influences on the structure of human cognitive abilities. I believe such a revision to be imperative if research on intelligence is to move forward.

Without a revised theory of intelligence, our understanding of human cognitive abilities is inherently one-dimensional. It is necessary to "transcend *g*," to use **Flynn's** phrase, in order to adequately characterize the complex nature of relations among cognitive abilities. Within the current individual-differences framework of the general factor, correlation among abilities is expected. But this correlation structure represents only one view of relations among cognitive abilities. Neurobiological and sociological data provide different views, particularly for fluid cognitive skills. Like a holographic image when tilted at an angle or the reflection in a fun-house mirror as the carnival-goer moves from side to side, the one-dimensional individual-differences structure of the general factor comes apart when examined in light of historical and neuropsychological data. The approach outlined by **Flynn** of a three-dimensional general factor-architectonic-sociological model begins to provide the necessary frame within which to array the increasingly varied and complex findings of intelligence research. Such a model will ultimately reconcile diverse and seemingly contradictory findings in the study of intelligence. These include, among others, findings from historical data on long-term trends in cognitive abilities and from developmental neuroscience examinations of the structure of human cognitive abilities. Although it is beyond the scope of this response to develop this model further, it is hoped that Flynn's call for a symposium on the future of intelligence research will be heeded and will array the requisite expertise needed for the advancement of theory in the study of intelligence.

Developing and refining a multidimensional model of intelligence is a very high priority given the long-standing and influential profile of the general factor. As noted by **Ford**, understanding aspects of cognition that may be more amenable to environmental influence has been and remains a high priority for researchers studying the effects of early experience and early intervention for children facing psychosocial or biological adversity. A revised and expanded model of intelligence that incorporates multiple levels of influence can provide some explicit indications of how and in what ways early experience may have its effects. Furthermore, as noted by Ford, longitudinal studies of early, highly structured experiential interventions to influence the developmental course of intelligence, particularly those using randomized designs, present an unparalleled data source for ongoing examination and revision of a multidimensional model of intelligence.

Of course, as **Anderson** makes clear in his commentary, the study of development can be seen as a unique source of variance in intelligence, one that is distinct from individual differences associated with the general factor. I agree to some extent with Anderson's approach but feel that it may make too sharp a distinction. In contrast to Anderson, I believe it is necessary to fully incorporate neurobiological factors, as well as sociological factors, when considering development in context. For my own part, I also find the role of emotion and stress in cognition to be considerably underdeveloped and an area of research likely to yield valuable information regarding influences on cognitive development, particularly for children facing early psychosocial adversity.

As noted by **Wilke**, the model presented in the target article suggests new directions for research that, if fruitful, will be of both basic and applied science value. Wilke describes two examples of the types of neuroscience research that might begin to provide evidence relevant to the model. He also raises important questions regarding the relation of the model to various brain structures. Almost certainly, a more comprehensive neural network approach that incorporates relations among multiple brain areas will be needed to characterize complex excitatory and inhibitory activations associated with fluid cognitive processes and their relation to other cognitive abilities. Advances in the study of cognitive aging, particularly the study of frontal-parietal connectivity in memory decline in typical aging and dementia (Buckner & Wheeler 2001; Hedden & Gabrieli 2004), clinical neuropsychological work on the role of specific areas of frontal cortex in memory deficits (Stuss & Alexander 2005), findings from training studies of working memory (Olesen et al. 2004), and findings regarding the role of frontal-striatal connectivity in self-regulation and cognitive control (Mink 2003), provide examples of the ways in which interrelations among multiple brain areas influence human cognition. It is hoped that the developmental neuroscience perspective on fluid cognitive abilities provided by the target article will ultimately inform and be informed by continued work of this type.

R3. WM, EF, and gF: How similar, how different?

For theory development in the study of human cognition to move forward, it is necessary to come to some consensus regarding terms and constructs. To my mind, what is perhaps the most pointed critique of the target article concerns the idea that I did not differentiate thoroughly enough among gF, WM, and EF; that I overemphasized similarity among them and downplayed the distinctiveness of each. Several commentators (**Benga; Birney, Bowman, & Pallier** [**Birney et al.**]; **Burgess, Braver, & Gray** [**Burgess et al.**]; and **Heitz, Redick, Hambrick, Kane, Conway, & Engle** [**Heitz et al.**]) suggest that by focusing on fluid cognition more generally rather than on distinct cognitive abilities, key issues in the study of human cognition were overlooked. To set the stage for the discussion that

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follows, it is important to note that I chose a somewhat broad level of resolution when characterizing fluid cognitive abilities in order to highlight the extent to which overlapping processes of working memory, attention shifting, and inhibitory control are distinct from more automatized and crystallized aspects of cognition. It was not my intention for readers to come away with the impression that I believe fluid cognition to be a unitary construct, isomorphic with gF, and dependent exclusively upon the prefrontal cortex. In fact, I was fairly explicit on the differentiation of distinct aspects of fluid cognition and the role of diverse brain regions in fluid abilities (see sect. 2.1). I think my central point – that fluid aspects of cognition have been taken in many instances to be highly similar, if not identical to general intelligence, but somewhat paradoxically have shown patterns of change across individuals and historical cohorts that clearly dissociate them from general intelligence – is one well worth making. But it is made within a shifting definitional sea. What is referred to as working memory by Kyllonen and Christal (1990) would seem to map only imperfectly onto working memory as defined by Baddeley (1986) or executive attention as defined by Posner and Rothbart (2000).

In part, but only in part, definitional issues in the study of fluid cognitive abilities result from the fact that researchers use different terms to describe constructs that are highly similar. Sorting out the similarity from the difference in these terms is no small task. For my own view, as well as that of others (Miyake et al. 2000), WM is a distinct component of an overarching EF construct that also contains inhibitory control and attention-shifting functions. Several of the commentaries provide some valuable analyses examining these different aspects of fluid cognitive abilities. In the data of **Burgess et al.**, **Demetriou**, **Viskontas & Holyoak**, and **Zook & Davalos** and the critiques by **Benga**, **Birney et al.**, and **Heitz et al.**, readers are provided with very thoughtful analyses of relations among constructs. However, several commentators confidently proclaim gF, WM, and EF to be distinct, an idea that no doubt has some validity, but one that available evidence does not clearly support.

R4. The potent combination: Working memory and inhibitory control

Burgess et al. provide an illuminating example that builds upon the analysis supplied by Gray et al. (2003) to indicate that both gF and WM span are related to a specific pattern of brain activity associated with *n*-back working memory trials that contain a strong interference component (lure trials). That gF and WM span show similar relations to brain activity associated with lure trials in an *n*-back working memory task, more so than with target and low-interference trials, is highly consistent with the presumed overlap of WM and gF. It does little, however, to differentiate the distinction between these two constructs. It does perhaps help in some ways to differentiate the various components of EF, although the inclusion of a trial type of high interference but low working memory demand would be helpful in making inference here. Had such a trial type been included, the results would likely continue to provide support for the idea that it is the combination of high working memory demand with the need to inhibit interference that is a central aspect of cognitive competence.

The analysis by **Burgess et al.** suggests that the maintenance of information in working memory and the inhibitory control aspects of EF are distinguishable but when combined present a highly meaningful pattern of brain activation. Similarly, the analysis by **Heitz et al.** indicates that inhibitory control ability as measured by a flanker task reliably distinguishes individuals with high WM span from those with low WM span. In both instances, the authors' findings indicate that the executive functions of working memory and inhibitory control are combined within persons into something like a "unitary" fluid cognitive construct. As outlined in the target article, various sources of evidence indicate that in combination these aspects of cognition possess a powerful relation to real-world ability – one that is distinguishable from g and essentially embodied in constructs such as working memory capacity (Engle 2002) and executive attention (Posner & Rothbart 2000) and well represented in Diamond's (2002) work on EF in early childhood.

The role of working memory/inhibitory control in cognitive competence (without an underlying concern to differentiate the constructs) is also clearly presented and shown to apply across the life span in the insightful analyses by **Viskontas & Holyoak** and **Zook & Davalos**. Both of these commentaries provide highly useful data indicating the applicability of a fluid cognitive approach to the study of cognitive aging. Viskontas & Holyoak introduce the construct of relational complexity, a construct denoting high working memory demand but also perhaps something more, and present data to indicate that tasks that combine relational complexity with inhibitory control are particularly difficult for older adults. Furthermore, operationalization of inhibitory control in the analysis by Viskontas & Holyoak through the use of superficially related semantic items that interfere with relational processing is similar to the use of lure trials to generate interference in the analysis by **Burgess et al.** In this way, Viskontas & Holyoak's analysis provides further evidence for a convergence of data on the combined executive functions of working memory and inhibitory control as central aspects of cognitive competence.

Viskontas & Holyoak also provide some indication that individuals with disruption of a frontal-temporal cortical network have difficulty with even simple relational complexity when presented with a verbal analogy with a semantically related distractor. Here, the use of verbal analogies may be an important feature of the design. It would be valuable to know whether similar results are obtained with numerical or spatial stimuli. If so, these data suggest, as with the analysis by **Burgess et al.**, that the potency of the interference effect is inversely related to WM function. Of further interest in Viskontas & Holyoak's analysis is the extent to which relational complexity, although seemingly a manifestation of working memory ability, may be dependent on processes beyond the EF of working memory that might be aspects of gF or g, such as abstraction ability or decoupling abilities described by **Garlick & Sejnowski** and **Stanovich** (discussed in sect. R8).

Similar to the effect of chronological age on the combined working memory/inhibitory control function noted by **Viskontas & Holyoak**, commentators **Zook & Davalos** provide cross-sectional data for individuals between the ages of 5 and 80+ years on the Tower of London (TOL) task. The TOL is a widely utilized measure of EF that, while dependent on WM demand, has been shown by Miyake et al. (2000), in the somewhat simpler form of the Tower of Hanoi, to also be dependent on inhibitory control. The finding that the ability to solve the task efficiently is reduced at the extremes of the life span, when cortical networks associated with the prefrontal cortex (PFC) are undergoing rapid change, provides further suggestion for the need to examine fluid cognitive ability independently of general intelligence. Indeed, this is exactly what Zook et al. (in press) did in individuals at the upper end of the life span. Consistent with some of the primary arguments of the target article, they found that fluid cognitive measures did indeed differentiate older from younger adults, and that this differentiation was present on a measure of fluid intelligence and measures of EF (the TOL and the Wisconsin Card Sorting Task [WCST]) but not crystallized intelligence. Of further interest from the perspective of the target article would be prediction from measures of fluid cognition and crystallized intelligence to aspects of social competence in older adults.

R5. Attention

Although in combination working memory and inhibitory control appear to play a powerful role in cognitive competence, attention is an aspect of fluid cognitive functioning that was not well characterized in the target article. The commentary by **Cowan**, however, provides a very useful introduction to the study of attention and fluid cognition. Specifically, Cowan's focus on the role of attention in information storage provides a comprehensive model for what I consider to be the attention-shifting component of EF. The cognitive ability to shift attention between bits of information held in short-term store and to use attention to maintain that information in storage is a key aspect of fluid cognitive function that is not represented by working memory or inhibitory control per se.

What is also compelling in **Cowan**'s approach is the explicit incorporation of relations among anterior and posterior brain regions in fluid cognition. As noted by Cowan in his commentary, and as stated in the target article, findings from brain imaging and electrophysiological recording clearly indicate the involvement of anterior, posterior, and subcortical brain regions in fluid cognitive tasks. Cowan's model details a specific role for posterior brain regions in information storage, along the lines of the phonological and visual-spatial loops in Baddeley's (1986) model. In addition to Cowan's work reviewed briefly in his commentary, work by Dehaene and collaborators also provides evidence for a parietal-frontal network in fluid cognition, in this instance in relation to the solution of simple mathematics problems and number processing (Dehaene et al. 2003; Simon et al. 2004). Work from this group suggests that distinct areas of the parietal lobe, in combination with prefrontal cortical areas, are involved in distinct types of mathematical cognitive activity. Similarly, work by Buckner (2004) indicates frontal-parietal connectivity in memory function in typical aging and dementia. Here, Cowan's emphasis on the distinction between storage and processing may be particularly useful for understanding the role of fluid cognition in learning and memory.

R6. An alternative position: Duncan's adaptive-coding model

As a counterpoint to the drive to differentiate working memory, inhibitory control, and attention shifting in the study of human cognitive abilities, it is necessary to consider John Duncan's adaptive-coding model (Duncan 2001; Duncan & Owen 2000). In Duncan's model, fluid cognitive processes are essentially unitary, and differentiation of working memory, inhibitory control, and attention shifting is not a realizable goal (at least as seen from the perspective of cognitive neuroscience). This is because these cognitive processes are understood to be dependent upon a shared prefrontal cortical network characterized by neurons that are highly adaptive to task demand. Specifically, as shown in findings from a number of brain imaging and single-cell recording studies, mid-dorsal lateral and ventral lateral PFC and dorsal anterior cingulate cortex (ACC) compose a cortical network comprised of neurons that are recruited by a variety of cognitive tasks. Whether in response to information maintenance, attention shifting, delayed response, response inhibition, or any of a number of fluid-type information-processing abilities, neurons in the cortical network adapt to support the behavior. In Duncan's model and data, this adaptive nature of neurons in the PFC network provides for a common processing substrate for all fluid cognitive abilities such that "working memory, selective attention, and (cognitive) control are simply three different perspectives on the same underlying processing function" (Duncan 2001, p. 824).

Although the adaptive-coding model might be characterized in some ways as overtly reductionist (i.e., if seemingly diverse aspects of fluid cognition share a common adaptive processing substrate, then they will be indistinguishable behaviorally), it is, according to Duncan, consistent with a body of clinical and brain-imaging evidence indicating the difficulty of separating fluid functions into well-specified components at the behavioral and neurological levels. At the very least, an important direction for researchers interested in the differentiation of WM, EF, and gF will be to reconcile behavioral and neuroscience data to identify unity and diversity in brain-behavior relations associated with individual differences in fluid cognitive abilities. Here the analysis by Gray et al. (2003) (as briefly described in **Burgess et al.**'s commentary) appears to be a valuable example (and one that Duncan [2003] has commented on). In that analysis, increases in levels of activation in the dorsal lateral prefrontal cortex (DLPFC) in response to a specific aspect of the task (lure trials), rather than differences in brain regions activated during less demanding aspects of the task, were related to differences in gF and WM span.

In contrast to the findings by Gray et al. (2003), however, an experiment by McDonald et al. (2000) revealed a somewhat similar finding for activation in response to a modified Stroop inhibitory control task but did so in distinct brain regions and with both positive and negative relations between brain activation and performance. Specifically, increased activation was observed in left DLPFC in response to the instruction to name the color (the more demanding task) relative to that observed in response to the instruction to name the word (the less demanding task). No differences in activation were observed in DLPFC, however, during the response phase of the task (the actual naming of the color or the word). In contrast, in the ACC, activation was observed in the response phase of the task but not the instructional phase. Furthermore, as with DLPFC, higher levels of activation were observed in the ACC for the more demanding response, to name the color, not the word. However, whereas activation in the DLPFC during the instruction phase was inversely related to errors in the response phase, activation in the ACC during the response phase tended to be positively related to error rates.

R7. Adaptability of adaptive coding: The role of stress and emotion

Reconciling the adaptive-coding model with behavioral and brain science models suggesting differentiation of fluid cognitive abilities is an important step in resolving the relation of fluid cognition to general intelligence. Duncan's adaptive coding model provides an overarching framework for the data he presented in a widely cited article indicating dorsal lateral prefrontal cortex to be the primary neural basis for general intelligence (cf. Duncan et al. 2000). However, interpretation of those data appears to be predicated on the assumption that gF = g and, as the numerous sources of evidence reviewed in the target article and presented in many of the commentaries indicate, this assumption is not tenable.

Furthermore, although the adaptive-coding model lends itself to a relatively straightforward interpretation regarding a neural substrate for aspects of cognition considered to be central to general intelligence, it also leads naturally to questions regarding factors that may influence the development and functioning of that substrate. In my estimation, as indicated in the target article, of strong interest here are aspects of stress and emotion that have been shown to influence neural circuitry important for fluid cognition both in human and in nonhuman animal models. However, it may be that aspects of emotion and stress are more relevant to working memory, inhibitory control, and attention shifting than to gF and to g per se. It is likely that further work can clearly elucidate relations between these aspects of experience in a way that can help to refine the differentiation of EF and gF.

The commentaries by **Demetriou**, **Benga**, and **Burgess et al.** provide valuable examples of the direction that work on emotion can take in the study of intelligence. Demetriou provides an example of the use of structural equation modeling to demonstrate the extent to which perceived competence and aspects of emotion are distinct partners in general intelligence. Of particular interest in Demetriou's analysis is that the sample is composed of adolescents. The majority of work on the structure of intelligence, and that associated with the relation of fluid cognitive abilities to g, is conducted with adults. But there are of course reasons to expect that aspects of emotion and sense of self may affect cognitive functioning differently at different points in the life course. Adolescence is a time of rapid biological and psychological change, as is early childhood and to some extent older adulthood. Such a developmental perspective is notably lacking in much research on intelligence, and it is hoped that analyses similar to those presented by Demetriou can explicitly model developmental relations among emotionality, perceived competence, and intellectual ability in ways that will ultimately help to clearly differentiate fluid cognition from general intelligence.

The commentaries by **Benga** and **Kaufman & Kaufman** provide explicit endorsements of the developmental perspective in the study of fluid cognition and general intelligence. Focusing on the combined inhibitory control/working memory construct, and following the work of Posner and Rothbart (2000) using the spatial conflict task developed by Gerardi-Caulton (2000), Benga suggests what has been clearly demonstrated by Diamond (2002) – that this aspect of cognition can be differentiated early in the life span and tracked developmentally. As well, the commentator suggests that inhibitory control/working memory may be particularly amenable to the influence of early life stress, as I suggested in the target article and as Blair et al. (2005b) continue to examine among preschool children living in poverty.

Kaufman & Kaufman, however, strike a more cautious note regarding the differentiation of fluid cognitive abilities in children. Noting the strength of the literature in cognitive-aging research, these authors suggest that the slow maturation rate of the PFC provides for a different perspective on fluid cognition in young children. In contrast, in the target article and elsewhere, I suggest that the slower maturation rate of the PFC highlights the distinctiveness of fluid aspects of cognition in children and renders these aspects of cognitive ability particularly amenable to the influence of emotion and stress (Blair 2002). Of course, such a situation increases the already considerable challenge of trying to measure fluid cognition accurately in young children. Fluid cognitive abilities have traditionally not been measured very well by standardized test batteries; in part, for the reasoning behind Kaufman & Kaufman's commentary: the assumption that these aspects of cognition are simply not developed in young children. According to the commentators, however, there are now a number of mental test batteries that contain comprehensive fluid cognitive assessments. Although I greatly appreciate this information and expect that the measures they describe provide a wealth of valuable data, I am still not convinced that all of them have been developed with as clear a conceptualization of fluid cognitive ability, independent of general intelligence, as might be needed. In part, this is because the knowledge base on fluid cognitive abilities, particularly in children, is in a process of rapid development. No doubt the measures outlined by Kaufman & Kaufman assess key aspects of fluid cognitive abilities, but these measures may also contain assessments that are less central to fluid abilities and that will not combine in a way that can clearly measure what is most relevant to the study of the development of fluid cognition.

The role of emotionality, but not life stress, is also addressed by **Burgess et al.** and **Tzafestas**. Burgess et al. report negative relations between the behavioral activation system (BAS) subscales of Carver and White's (1994) behavioral inhibition system/behavioral activation

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system (BIS/BAS) measure and brain activation in the PFC and ACC across trial types on the *n*-back working memory task. This fascinating finding suggests that high levels of approach behavior, which are thought to be associated with risk for externalizing behavior problems and are themselves associated with EF deficits in children (Blair et al. 2004; Cole et al. 1993), may be associated with reduced activation in brain areas associated with fluid cognitive abilities. Furthermore, the finding of the effect across trial types and controlling for gF suggests a general relation between neural activity in cortical networks associated with the PFC and a fundamental aspect of personality in young adults.

In our work on the BAS, we have shown in preschool children that high level of BAS (as measured by a version of the scale adapted for parent report) is associated with lower level of EF, lower level of hypothalamic pituitary adrenal axis arousal, and higher level of parasympathetic autonomic nervous system (ANS) reactivity (Blair et al. 2004). Similarly, Sutton and Davidson (1997) have shown that higher level of BAS in young adults is associated with greater relative left prefrontal brain activity as measured using electroencephalography (EEG). In combination, these results provide evidence for the relation of BAS to aspects of brain and physiological function important for fluid cognitive abilities. Further work is required to examine the complexity of these relations, their developmental pathways, and the extent to which high approach may be indicative of greater processing efficiency and perhaps greater fluid cognitive ability in some individuals but indicative of a more reactive personality type and reduced fluid cognition in others.

In a somewhat similar vein, **Tzafestas** presents a rather unique neural physiological model of the relation of fluid intelligence to crystallized intelligence in which emotion and goal directedness are seen to play important roles in the self-organization of neural networks underlying higher-order cognitive function. Focusing perhaps more on fluidity of neural processing rather than fluid cognitive processes per se, the role of individual experience both externally and internally generated looms large in the model. I suggest in the target article and elsewhere (Blair 2002), that high levels of stress and emotionality may lead to patterns of neural activity that serve through reciprocal relations among environment, behavior, and physiology to increasingly constrain cognition and behavior. Specifically, high levels of early life stress are thought to lead to problems with emotion regulation and to increase the likelihood of emotional reactive rather than effortful cognitive patterns of response to stimulation. In contrast to Tzafestas's model, however, I believe the neural organizational effects of early stress on cognition pertain more to fluid than to crystallized abilities. Of course, to the extent that fluid and crystallized functions are interrelated, it would perhaps be expected that emotion-related and stress-related influences on the neural physiology of fluid cognition might also be represented in crystallized skills. However, I believe such a model may be too encompassing and decontextualized, not taking into account the wide variety of experience that could lead to advances or delays in crystallized ability independent of fluid cognitive skills.

In contrast to a focus on the relation of emotion to cognition in research on personality and intelligence, it should be noted that **Anderson** articulates an alternative position in which work on stress and emotion, let alone neuroscience, has little place in the study of intelligence. In contrast to Anderson's position, however, I believe that the careful working out of relations of brain structure and neurophysiology to distinct aspects of fluid cognition is essential. It is perhaps one way that we can come to some very detailed understanding of the constructs and in particular the role of experience in the development of cognition and personality.

Given the ubiquitous behavior genetic finding of high heritability for intelligence as well as the recent extension of this approach to gray matter volumes and IQ (Thompson et al. 2001; Toga & Thompson 2005), it is necessary to clearly establish relations among overlapping but distinct aspects of cognition and personality and overlapping but distinct neural structures and functions. This is particularly imperative given the unfortunate interpretation of heritability employed by many behavior genetic researchers to mean a fixed and unchanging aspect of the individual (for critiques, see Dickens & Flynn 2001b; Gottlieb 1998; and Wahlsten 1996). For example, the finding that gray matter volumes, particularly those in the PFC, are highly related to general intelligence, and like general intelligence, highly heritable (Thompson et al. 2001), tells us very little about the process of development or the role of experience in that process. As always, the equal-environments assumption looms large for inference derived from twin studies. This would seem particularly so for the study of brain development as principles of neural development and synaptic plasticity suggest the important role of experience in determining cortical volumes and functional connectivity.

A highly valuable behavior genetic case in point is provided by findings indicating high shared environmental influence on performance and full-scale Wechsler Intelligence Scale for Children (WISC) IQ in 7-year-old children from low socioeconomic status (SES) homes but high heritability in children from middle-SES and upper-SES backgrounds (Turkheimer et al. 2003). This evidence is on par with that of rising mean IQ in its indication that assumptions regarding the nature of the general factor and influences on it, particularly genetic influences, are in need of revision. I believe that such a revision will likely involve some incorporation of the idea that high levels of early adversity, particularly those associated with stress reactivity, impact in significant ways the development of neural structures and functions associated with fluid cognition and thereby the nature of relations among human cognitive abilities.

R8. General intelligence: What is it? What is it not?

Which leads to what for me is one of the most pressing questions raised by the target article and addressed to one extent or another by several of the commentaries: namely, if fluid cognitive abilities, working memory, inhibitory control, and attention shifting are not *g* and perhaps not even gF, then what exactly is *g*? Where does the evidence reviewed leave us with respect to *g*? Several suggestions were made regarding this point. **Birney et al.** suggest *g* to be only of historical interest, and I posed the strong statement at the outset of this response suggesting a waning of the influence of *g* as an explanatory construct.

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But it would seem that the relation of WM and EF to *g* and to gF is too strong and too seductive for *g* to move rapidly to the margin. There is a strong pull not only to equate WM and gF but to then think we have gotten very close to the elusive heart of general intelligence when identifying this relation.

Among the present commentators, the group represented by **Heitz et al.** stated previously that WM may be gF (Engle 2002). However, in subsequent reports and in their commentary on the target article, the authors are very clear that WM does not equal gF, stating that approximately half of the variance in gF is attributable to WM. (This finding is somewhat discrepant, in what appear to be expected ways, with that reported in a meta-analysis indicating the relation to be closer to a quarter of the variance [see Ackerman et al. 2005 and associated commentary].) What this means for definitions of *g* and gF, however, is not exactly clear. Heitz et al. state that they are focusing their efforts on executive control of attention, which would seem to be something along the lines of the combined working memory and inhibitory control function that appears to be a key, perhaps the key, aspect of the relation of fluid cognitive abilities to real-world competence independent of *g*. But, to some extent, it seems that the more rigorously one defines fluid cognition, the less clear *g* and gF become.

Other commentators, of course, have a different take on what is unique to *g* and gF. The approach of **Garlick & Sejnowski** is of particular interest in that they of all the commentators most explicitly take issue with the relation of WM and EF to *g* and gF (while mistakenly claiming that I describe the WCST as a measure of fluid intelligence.) I very much appreciated their insight that even the easiest of Raven's matrices items, which make limited demands on WM, are measures of fluid intelligence and that the central aspect of gF may be abstraction ability. However, it is open to question whether abstraction as a thing in itself would prove tractable as an object of study and, even if so, whether it would prove to be a higher-order construct dependent on working memory, inhibitory control, and attention shifting. Similarly, **Stanovich**, who in contrast to Garlick & Sejnowski took no issue with the idea that aspects of EF as instantiated in gF would fracture quite naturally from *g* and gC, proposed cognitive decoupling as the possible relevant aspect of gF. As with abstraction, this construct would seem to have high face validity, but the extent to which it would prove tractable as a measurable aspect of cognition distinct from lower-order WM and EF processes remains to be seen. However, it seems highly promising as a target of inquiry.

Furthermore, it is possible that those of us who are entranced by the relation of WM and EF to *g* and gF are simply barking up the wrong tree – or, more appropriately, that we have a tree of our own that we should be satisfied with and stop sniffing around the *g* factor. According to the analysis by **Johnson & Gottesman**, the gF-gC characterization of intelligence is incorrect; Vernon's (1965) verbal-educational (v:ed) and spatial-mechanical (k:m) characterization of the structure of intelligence provides a more accurate fit to the data and description of what *g* is all about (Johnson & Bouchard 2005). Although Johnson and Bouchard's analysis appears to be very well done, it is interesting that, in order to obtain a better fitting model with the Vernon approach, an additional memory factor at the second stratum and most importantly an additional visual-spatial ability, mental rotation factor at the third stratum were needed. The presence of the visual-spatial ability, mental rotation factor at the third stratum is fascinating in that spatial ability and mental rotation both substantially involve working memory and as such can be considered fluid cognitive functions dependent upon a prefrontal-parietal cortical network (Constanidis & Wang 2004; Smith & Jonides 1999). Accordingly, although controversial, I would suggest that perhaps the Vernon–Johnson model does indeed provide a more accurate description of the structure of intelligence to the extent that it helps to reinforce the point that reconciling the relation of fluid cognitive ability to general intelligence will continue to be a major aspect of the redefinition of what matters most in the study of human cognitive abilities. The need for adjustment of the Vernon–Johnson model to accommodate four items assessing visual-spatial ability suggests that further examinations of the Vernon structure of intelligence with test batteries containing a greater number of visual as well as verbal working memory, inhibitory control, and attention-shifting items would be warranted. My prediction for these studies is that items assessing fluid cognitive abilities will continue to cause problems for model fit.

R9. Agree to disagree

Although I find myself in agreement with much of the commentary on the target article, there are a few points raised by some commentators that I have to agree to disagree with. Specifically, **Kovacs, Plaisted, & Mackintosh** [**Kovacs et al.**] question the basic thesis of dissociation. Although sympathetic to the need for further investigation of fluid skills, particularly in children, these commentators suggest that the target article provides no compelling evidence of dissociation of fluid skills from general intelligence. To a large extent, they attribute this to a perceived tendency on my part (1) to associate general intelligence with crystallized rather than fluid abilities, and (2) to regularly interchange the terms general intelligence and *g*, and fluid cognition and gF.

As to the first point, nothing in the text cited by **Kovacs et al.** suggests that I consider gC to be identical to *g*. The crucial point concerns not the relation of *g* to gC, a relation that no one disputes, but the absence of relations of gF, in a number of specific instances, to both gC and *g*. If indicators of gF are unrelated to *g* and also to gC, then it follows as clearly as night follows day that gF cannot be *g*. Which is not to discount *g* or gC so much as to credit aspects of gF independent of *g* with a hard earned legitimacy.

As to the second point concerning the interchangeable use of terms relating to aspects of cognitive function, I find myself cornered by these commentators' skillful wielding of Occam's razor. I can only plead that I find the epistemological distinction between universal and differential constructs to be a differentiation unto itself that is of questionable utility. I believe that most scientists would agree that universal and differential constructs are at least moderately interconnected, and that the differential construct serves as our best guess about the nature

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of the universal construct. Although one can distinguish among the terms general intelligence and *g*, and fluid cognition and gF, we must allow for some interchangeable use among the terms or the research enterprise becomes more philosophic than empirical. In particular, although dissociation of two processes may or may not inform us about the correlation between them, it certainly tells us quite a bit about the relevance of the particular instance of the differential to real-world competence. Introducing the differential construct handedness into the unfortunate missing-limb analogy, it becomes quickly obvious that when an individual loses the dominant hand, be that right or left, functioning rapidly deteriorates. It is cold comfort to know that the universal construct of overall strength remains intact. I suggest that in this and most, if not all instances, it is preferable to remain rooted in the functional realm of the differential rather than the ethereal realm of the universal. I believe this to be the case particularly with intelligence research, which has spent far too much time with the ether. A very useful description of the tension between the abstract and the concrete in scientific inquiry is provided by A. N. Whitehead in his description of the Fallacy of Misplaced Concreteness (1925/1948). Although Whitehead's fallacy was formulated within a general critique of the scientific endeavor, it is particularly applicable to psychological research and to research on intelligence specifically.

Similarly, as a student of the history of science (B.A. 1984, McGill University), I very much enjoyed **Voracek**'s characterization of the independent fluid cognitive construct as a phlogiston theory. Although in hindsight, the scientific past can appear as a repository of cockamamie theories and failed ideas, such a view provides a highly inaccurate picture of the process of scientific inquiry. Phlogiston, for example, represented a logical extension of alchemical thinking and principles that was, as is its successor, modern chemistry, based in the empirical approach. Certainly one can discern a positivist and progressive history to the advance of science, but it is a history characterized by many twists and turns. Accordingly, to my way of thinking, as an explanatory construct, the theory of general intelligence possesses a much greater similarity to phlogiston than does work on fluid cognition. In fact, the *g* factor, as a poorly defined entity emerging from factor analysis of diverse tests of mental ability, bears a striking resemblance to the hypothetical phlogistic material used to explain the occurrence of combustion. Namely, prior to the identification of oxygen and the mechanisms of combustion, phlogiston served as a working explanation for the effect that lost its utility only when it ceased to be consistent with observation and experiment. At that point, due mainly to unceasing defense by its champions, it increasingly became more of an impediment to scientific progress than anything else.

Unfortunately a phlogiston-like situation appears to be the case with some of the research on *g*. I take as a case in point **Voracek**'s seeming fascination with the Flynn effect, and what seems to be an overarching desire in his commentary to discredit this well-established phenomenon. The commentator's focus on this one piece of evidence supporting the dissociation of fluid cognition from general intelligence is of further interest in that the data that he offers to refute the effect are derived from a sample of psychiatric patients. The target article, however, reviews a considerable body of evidence indicating that a number of psychiatric disorders, in particular schizophrenia, but also more common disorders, such as anxiety and depression, which presumably would make up the bulk of the author's sample, are frequently characterized by fluid cognitive deficits in the presence of crystallized ability and general intelligence in the normal range. Accordingly, the absence of the generational effect on fluid cognition in Voracek's data would seem to provide additional support for the overall hypothesis of dissociation. The absence of the increase in his sample would be expected.

R10. Conclusion

Without question, further conceptual and empirical advances are needed to address relations among fluid cognitive abilities and relations of fluid cognition to general intelligence. In this work, I suggest that a developmental neuroscience approach that clearly incorporates the role of emotion-related and stress-related processes in a comprehensive understanding of the structure and function of neural systems associated with fluid cognitive abilities is most likely to yield findings of lasting basic and applied science utility. Furthermore, at the outset of this essay, I raised the possibility that, due to an increasing lack of specificity, the general factor of intelligence is of decreasing utility as an explanatory construct and that an expanded and revised theory of intelligence is needed that can reconcile traditional conceptions of intelligence with new data and perspectives on fluid cognition. Certainly what this reconciliation will look like remains to be seen. However, it may be that much of the information necessary for the endeavor is currently available. In particular, although researchers have been somewhat less than enthusiastic about the moderate correlation between the general factor and measures of inspection time and reaction time (IT/RT), it may be that these relations tell an important part of the story. Given the presence of sociological and neurobiological influences on fluid cognition and the similarity of fluid cognition to general intelligence, IT/RT measures, as indicators of general speediness and faster, more efficient brains, may be what *g* as traditionally conceived is really all about. Such a conclusion for *g* may be more modest than many may have hoped for, but if correct, the result could lead one to contemplate a complex set of associations among multiple variables relating to neural efficiency, neural structure, emotion, stress, and experience. Such a complex model, although in need of further theoretical underpinnings and empirical support, may perhaps be able to adequately account for the seemingly all-encompassing nature of general intelligence, as traditionally conceived. To some extent, it would seem that the general factor as conceptualized over the past 100 years or more has simply proven too monolithic in its current form to be of continued scientific value. This of course in no way changes the fact that the construct embodies a great deal of what matters most in the study of human behavior. Indeed, it suggests that if the construct as it is currently known is beginning to fade into the scientific sunset, it certainly isn't going with a bang, but neither is it going with a whimper. At best, the report of its death would have to be greatly exaggerated.

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The letters "a" and "r" before author's initials stand for target article and response references, respectively.

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