dissociation of two processes in this sense tells us nothing about the correlation between them. For example, measures of the strength of people's left hand will most probably correlate with those of the right hand, and this is not affected by the fact that (a) people can do things with their hands in parallel or (b) that people can lose their arms separately in accidents. Let us assume that a measure of the strength of the right hand shows a very high correlation with measures of the strength of the left hand. It is right to conclude that they measure the same *thing*, if by a "thing" we mean a latent causal variable that explains the covariation – in this case, perhaps general muscular make-up. But it would be foolish to conclude that they measure the same *thing* in the universal sense, since it would mean that we are born with only one hand. But we are born with two, and we can lose them one by one. In short, they can be dissociated, independently of the correlation.

The architecture of cognition does not determine the structure of correlations between performance on various tasks, and the latent variable structure of between-subject differences does not determine the architecture of cognition. Hence, the correlation matrix, or the factor (latent variable) structure of different tasks, tells us nothing about whether they can be dissociated in the cognitive psychologist's sense, or vice versa.

This leads back to the difference between the theoretical status of variables like *g* and Gf, or general intelligence and fluid cognition. Fluid cognition and general intelligence are universal constructs that give causal explanations at the level of the individual, whereas *g* and Gf are differential constructs that account for the common variance between various tests or tasks. Nevertheless, to be able to choose between different factorial solutions, differential constructs (such as Gf) must be grounded in universal ones (such as fluid cognition). But the methodological differences and the different scope of explanation must be kept in mind. If we pay attention to the difference between the (universal) constructs of general intelligence and fluid cognition, on the one hand, and the (differential) constructs of *g* and Gf, on the other, we will be in a better position to consider whether any of the two pairs can be dissociated.

NOTE

1. We prefer to use the "Gf" abbreviation used by Cattell and Horn to signify fluid intelligence; Blair's use of "gF" is unusual.

Fluid intelligence as cognitive decoupling

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Abstract: The dissociation of fluid cognitive functions from *g* is implicit in the Cattell-Horn-Carroll gF-gC theory. Nevertheless, Blair is right that fluid functions are extremely important. I suggest that the key mental operation assessed by measures of gF is the ability to sustain mental simulation while keeping the relevant representations decoupled from the actual world – an ability that underlies all hypothetical thinking.

Blair displays immense scholarship in marshalling a broad array of evidence in neurobiology, psychometrics, and developmental science relevant to understanding the role of fluid cognition in cognitive theory. His main thesis appears early in the target article: "[D]issociation of fluid cognitive functions from other indicators of mental abilities through which *g* is manifest suggests that some reconceptualization of human cognitive competence is needed and may indicate instances in which *g* has reached or exceeded the limits of its explanatory power" (sect. 1.1, para. 3). Although I largely agree with this thesis, I think that most of the work driving the field toward it has already been done in the form of the modern synthesis of intelligence research represented by the Cattell-Horn-Carroll (CHC) gF-gC theory (Carroll 1993; Cattell 1963; 1998; Geary 2005; Horn & Cattell 1967; Horn & Noll 1997; McGrew & Woodcock 2001).

The reason I make this somewhat deflationary comment is that many of the dissociations Blair discusses are easily handled by invoking the CHC theory. In many of the examples discussed in the target article, fluid intelligence dissociates somewhat from general intelligence because the latter is estimated from an amalgam of gF and gC tasks, and the particular effect discussed has differential impact on gF and gC. The result will be gF somewhat dissociated from *g* (but not as much as it dissociates from gC). This is certainly the case when we examine the secular rise in IQ known as the Flynn effect. Measured in standard units, the rise in gF is larger than the rise in *g* because general IQ measures contain components of crystallized intelligence which has not risen at all. Fluid intelligence dissociates from *g* in the Flynn effect because the secular rise is differential across gF and gC.

It is likewise with Duncan's demonstrations of the effects of damage to the dorsolateral prefrontal cortex (Duncan et al. 1995; 1996). One could say that these demonstrate that gF dissociates from *g*, but it is more parsimonious to simply say that the Duncan demonstrations show what CHC theory predicts: that, in certain cognitive domains, gF will dissociate from gC.

Nevertheless, I am in complete agreement with Blair that fluid functions are extremely important and that they are environmentally sensitive. I believe that research is homing in on the critical underlying operation(s) that makes fluid intelligence so critical to mental life. I have argued (Stanovich 2004) that the mental operation is one that accounts for a uniquely human aspect of our cognition – the ability to sustain an internal cognitive critique via metarepresentation. That extremely important mental operation is the decoupling of cognitive representations.

Cognitive decoupling supports one of our most important mental tasks: hypothetical thinking. To reason hypothetically, a person must be able to represent a belief as separate from the world it is representing. Numerous cognitive scientists have discussed the mental ability to mark a belief as a hypothetical state of the world rather than a real one (e.g., Carruthers 2002; Cosmides & Tooby 2000; Dienes & Perner 1999; Evans & Over 2004; Jackendoff 1996; Leslie 1987; Nichols & Stich 2003). Decoupling skills prevent our representations of the real world from becoming confused with representations of imaginary situations that we create on a temporary basis in order to predict the effects of future actions or to think about causal models of the world that are different from those we currently hold. Decoupling skills vary in their recursiveness and complexity. At a certain level of development, decoupling becomes used for so-called metarepresentation – thinking about thinking itself. Metarepresentation is what enables the self-critical stances that are a unique aspect of human cognition (Dennett 1984; 1996; Povinelli & Giambrone 2001; Sperber 2000; Stanovich 2004; Tomasello 1999). We form beliefs about how well we are forming beliefs, just as we have desires about our desires and possess the ability to desire to desire differently.

Sustaining cognitive decoupling is effortful, and the ability to run mental simulations while keeping the relevant representations decoupled is likely one aspect of the brain's computational power that is being assessed by measures of gF. Evidence that the key operation underlying gF is the ability to maintain decoupling among representations while carrying out mental simulation derives from work on executive function (e.g., Baddeley et al. 2001; Gray et al. 2003; Salthouse et al. 2003) and working memory (Colom et al. 2004; Conway et al. 2003; Kane & Engle 2003). First, there is a startling degree of overlap in individual differences on working memory tasks and individual differences in measures of fluid intelligence. Secondly, it is becoming clear that working memory tasks are only incidentally about memory. Or, as Engle (2002) puts it, "WM capacity is not directly about memory – it is about using attention to maintain or suppress information" (p. 20). Engle (2002) goes on to review evidence indicating that working memory tasks really tap the preservation of internal representations in the presence of distraction or, as I have termed it – the ability to decouple a representation and manipulate it. What has for years been called in the literature generic cognitive capacity is probably the computational expense of maintaining decoupling in the presence of potentially interfering stimuli (why we look at the ceiling sometimes while thinking hard in a noisy room). If this is indeed the critical gF operation, Blair is correct that it is extremely important, because it is the basis of all hypothetical thinking.

Fluidity, adaptivity, and self-organization

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Abstract: I propose a neuroscience and animat research-inspired model and a thought experiment to test the hypothesis of a developmental relation between fluid and crystallized intelligence. I propose that crystallized intelligence is the result of well-defined activities and structures, whereas fluid intelligence is the physiological catalytic adaptation mechanism responsible for coordinating and regulating the crystallized structures. We can design experiments to reproduce exemplified normal and anomalous phenomena, especially disorders, and study possible cognitive treatments.

The target article puts forth the hypothesis of a developmental relation between fluid and crystallized intelligence. I propose a model and a thought experiment to test this hypothesis. More specifically, I start from the biological assumption that the substrate of intelligence is a network of interconnected cells able to self-organize in response to external events, as well as due to endogenous dynamics. The biological properties of such networks may be summarized as follows: (1) individual cells are able to self-regulate in their local environment and in relation with neighbor cells, (2) individual self-regulation leads through self-organization to stable structures or cell clusters responsible for various functions, and (3) emergent cellular structures generally overlap, so that interactions between the emergent functions are partly unpredictable (Edelman 2004).

Within this configuration, the crystallized part of intelligence is the (static) result of the cellular structure's activity, while the fluid part of intelligence is the physiological potential for self-organization and network restructuring. In this sense, crystallized intelligence appears behaviorally well defined and thus "measurable," whereas fluid intelligence remains behaviorally ill-defined and not measurable alone, but only in relation with crystallized intelligence. This is because crystallized intelligence as measured on a particular task is the result of a more or less distinguishable structure that responds to regular tasks, while fluid intelligence is structurally hidden in the network, responds to novel or mutated tasks, and is finally responsible for new crystallized structures.

Fluidity in the cellular-network context can be established only through continuous adaptivity, that is, through constant change under environmental influence. Constant change thus is both history driven (i.e., developmentally cumulative in time) and situationally driven (i.e., highly interactive within a particular context). I should stress that environmental influence is qualified as influence by the individual perceptually and selectively (Steels & Belpaeme 2005). Furthermore, because perceptual schemas may be idiotypic, some influence may be endogenously generated and not provided by the environment (Varela et al. 1991). A number of additional issues on fluidity are also important to the mechanism. First, a necessary feature for physiological fluidity is that the mechanism is self-catalytic or that it acts upon itself, in the sense of changing itself upon every "change command"it issues to one of the structures it controls. This leads to cognitive aging, because future self-organization rates are always lower than the present ones, although the reason or the mechanism for this being so is not well understood. Secondly, such physiological or self-organizational fluidity is usually regarded as being goal directed. However, because nothing forces emergent structures or even individual cells to take just external inputs, it is safe to assume that some goals will be self-generated or plainly endogenous within the individual, which leads us to usual idiotypic selective networks, a well-known structure possessing self-organization capabilities. Finally, the role of emotion, although obviously important, is not clear yet. We assume that emotion acts as a channel of social influence, which has therefore the double potential to speed up learning or drive an individual mad. By design then, fluid intelligence uses three types of information: (1) idiotypic information as explained before, which alone yields autonomic responses; (2) social information that triggers and interacts with emotional responses; and (3) crystallized information that contributes cognitive responses or cognitive parameters to complex responses. Normally, all three types are coordinated and reach a balance through self-organization that allows for coherent manifest behavior. Dysfunctions in any part are however possible, in which case all kinds of anomalies may emerge.

Within the described structural setting, normal phenomena such as those described in the target article may be reproduced (Balkenius 2000; Burgess et al. 2001): continuous favoring of one activity by the physiological fluid mechanism corresponds to focused attention, selection of activity C each time activity A or activity B could be invoked corresponds to abstraction, abrupt switches from activity to activity could be attributed to external stress (i.e., to abrupt changes to environmental conditions), and so on. Deviations or anomalies are also possible under certain conditions: (1) Innate learning impairments (e.g., exclusion from a particular perceptual subspace) or persistent external manipulation (e.g., bombardment with particular stimuli) may lead to destabilization of the usual structures and stabilization of new, unusual ones, thus inducing marginal or deviant behavior. In extreme cases, this may also lead to culturally driven alienation of generations (as in the case of families being raised in prisons and other marginal social environments). (2) Extreme endogenous network dynamics may lead to cognitive disorders without biological lesions being necessarily involved. For example, extremely slow self-catalytic rates may produce behavior perceived as retarded, while extremely low responses to visual emotional cues may act as a predisposition to autism. In all of these cases, self-organization will lead anyway to stable structures, natural albeit unusual (but not abnormal). However, fluidity itself allows for some limited remedy for such cognitive deficits, because stabilized structures cannot utterly change but may be a bit perturbed: for example, dyslexic people may read with conscious effort, and autistic patients may follow a gaze with conscious effort.

We can therefore design experiments to (1) produce self-organization and emergent structures with the aforementioned model, (2) allow the study of extreme cases in limited conditions of the system parameters, (3) perform perturbation studies to identify the degree and range of resistance of emergent structures to external stress, and (4) produce behavioral anomalies either because the external stress is very high (typical brains in atypical environments, according to Blair) or because the endogenous dynamics are such that the lowest external stress level or even a complete absence of stress induces phenomena such as activity loops or activity isolation (atypical brains in typical environments, according to Blair). The interplay between external social stress and endogenous

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