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

factors is especially interesting and important to study because all social disorders may be thought of and studied as emotional disorders and as resulting from repeated broad changes (Nesse 1998). Finally, we can design experiments that will prompt proper cognitive treatments for such cognitive disorders, for example, enriching the environment with controlled stimuli in the case of simulated autism, so as to hinder isolation.

Mechanisms of fluid cognition: Relational integration and inhibition

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Abstract: Blair argues that fluid cognition is dissociable from general intelligence. We suggest that a more complete understanding of this dissociation requires development of specific process models of the mechanisms underlying fluid cognition. Recent evidence indicates that relational integration and inhibitory control, both dependent on prefrontal cortex, are key component processes in tasks that require fluid cognition.

As Blair notes, numerous studies have shown that fluid cognitive processes can be dissociated from general intelligence in individuals with prefrontal cortex (PFC) damage (Duncan et al. 1995; Waltz et al. 1999). Furthermore, Blair also presents evidence supporting the hypothesis that the development of fluid intelligence precedes and even "paves the way for the development of crystallized intelligence" (sect. 4.1, para. 1) (Cattell 1971; Horn & Cattell 1967). Others have observed that prefrontal cortex, which appears to be critical to fluid intelligence, plays a major role in cognitive development. For example, Damasio (1985) concluded that, "It seems probable that bilateral damage to the frontal lobes in infancy or childhood produces a more devastating effect on personality and cognitive ability than the same amount of damage sustained elsewhere in the brain at any time in the course of development" (p. 351).

The conceptual separation of fluid cognition from general intelligence sets the stage for more specific hypotheses concerning the processing mechanisms that support fluid cognition. Recent work on human reasoning supports the proposal that tasks requiring fluid cognition depend on specific functions of prefrontal cortex: the representation and manipulation of explicit representations of relations, and the capacity to inhibit responses based on salient but less complex representations (Robin & Holyoak 1995). In the target article, Blair cites a study by Waltz et al. (1999) in which we observed a decline in relational processing with frontal impairment. Specifically, patients with frontal-variant Frontotemporal Lobar Degeneration (FTLD) were able to solve problems that required processing a single relation at a time (e.g., understanding a simple relation such as "Mary is taller than Sally"); however, their performance fell to chance on problems that required integrating multiple relations (e.g., using the premises "Mary is taller than Sally" and "Alice is taller than Mary" to infer by transitivity that Alice is taller Sally).

Similar but less dramatic impairment of relational integration has been observed in Alzheimer's patients who display frontal signs (Waltz et al. 2004). Our lab has also found (Morrison et al. 2004) that patients with frontal-variant FTLD are severely impaired in solving even 1-relation verbal analogies when active inhibition of a semantically related distractor is required (e.g., PLAY:GAME:GIVE:? where the analogical answer PARTY competes with the semantically-related distractor TAKE). Solving the kinds of problems associated with fluid cognition thus requires both relational integration (a core function of working memory) and inhibitory control.

We have recently extended these findings by investigating relational integration and inhibitory control in younger, middle-aged, and older adults (Viskontas et al. 2004; in press). A general decline in working memory capacity with age is well documented (Craik et al. 1990; Dobbs & Rule 1989). Most of the evidence indicates that while primary or immediate memory capabilities, such as digit span, remain relatively constant throughout life, working memory processes that involve the actions of the central executive, such as manipulating information held in memory, are vulnerable to age (Craik et al. 1990). In our reasoning tasks (including transitive inference, and versions of Raven's Matrices problems), participants had access to all of the information needed to make inferences at all times; we thus minimized demand on short-term storage systems. However, we varied the number of relations that had to be manipulated to find a solution; as more relations had to be integrated, the central executive would be increasingly taxed. In addition, we varied whether or not a superficially similar distractor item was present to compete with the correct relational response.

We found that, as people age, their ability to manipulate multiple relations declined. Moreover, the number of relevant relations interacted with the requirements for inhibitory control, such that older people were most vulnerable when high levels of relational complexity were coupled with high need for inhibition of superficially related alternatives (see Fig. 1).

Our results indicated that this apparent decline in processing capacity in working memory follows a gradual pattern: younger adults reached their working memory capacity when integrating four relations, middle-aged people had some trouble integrating three relations, and older adults had trouble integrating even two relations. This pattern of results suggests that aging does not produce a catastrophic failure in processing multiple relations, as was observed for patients with extensive frontal lobe degeneration (Waltz et al. 1999). Rather, the decline in relational

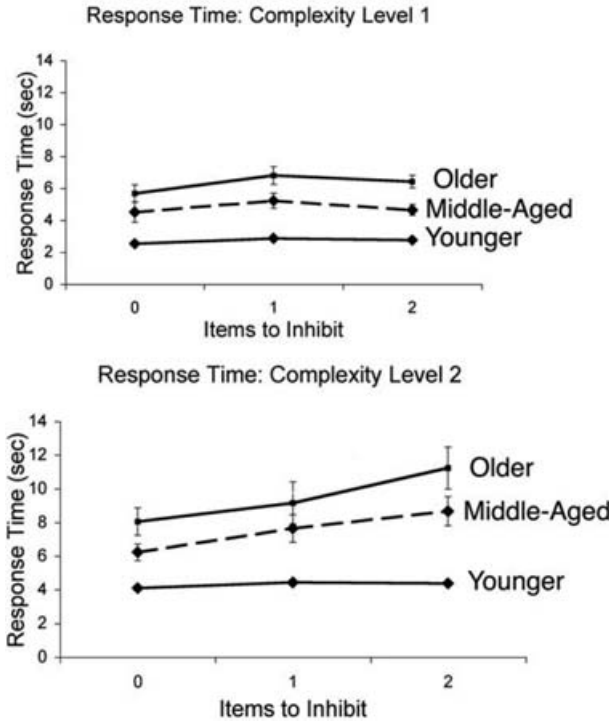

Figure 1 (Viskontas & Holyoak). Response time in the People Pieces Analogy task for three levels of inhibition at the first two levels of complexity for younger ($n = 31$), middle-aged ($n = 36$), and older ($n = 22$) groups (*error bars* depict standard error of the mean). Data from Viskontas et al. (2004).

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