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EXECUTIVE FUNCTIONS

Reflections on the Development of Executive Function: Commentary on Knapp and Morton, Munakata et al., Rueda and Paz-Alonso, Benson and Sabbagh, Hook et al., and Blair

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Introduction

Children's executive function (EF) is now recognized to be a key aspect of human development. Interest in the development of EF has increased dramatically during the past decade, in part because individual differences in EF measured in childhood have been found to predict a wide range of developmental outcomes, including school readiness, social functioning, academic achievement, and even mental and physical health.[1] Indeed, impairments in EF are prominent features of numerous disorders with childhood onset, including ADHD, autism and conduct disorder. At the same time, however, research on EF has yielded evidence of considerable plasticity or malleability, and EF is emerging as a primary target of interventions designed to promote healthy development. The articles included in this section[2-7] provide a brief survey of major themes in current research on EF, identify questions for future research, and reveal clearly why the study of EF and its development is of enormous importance both for a basic scientific understanding of human behaviour and for more direct efforts to improve the lives of children.

Research and Conclusions

The following five questions are central among the many issues raised in this set of articles.

1. How do we measure EF in childhood and across the lifespan?

Blair[2] highlights the need for “measures suitable for longitudinal research,” and Knapp and Morton [3] note that “tasks that are appropriate for testing EF at one age will not typically be suitable for testing EF in older children.” Munakata et al.[6] also make this point. Having measures that can be used across a wide age range is important if we want to compare EF across ability levels, whether age-related or not. Such measures also inform and are informed by our understanding of the structure of EF.

A major methodological advance in this area is the introduction of the new Cognition Battery from the National Institutes of Health (NIH) Toolbox for the Assessment of Neurological and Behavioral Function,[8,9] which includes measures of all three key aspects of EF: cognitive flexibility, inhibitory control and working memory. These measures include, respectively, a version of the Dimensional Change Card Sort,[10] a version of the Eriksen flanker task derived from the Attention Network Task,[11] and a List Sorting task derived from the Spanish and English Neuropsychological Assessment Scales.[12] The NIH Toolbox measures of EF are brief (less than five minutes each) and are suitable for use in repeated trials (with minimal *practice effects* for participants across the lifespan. Results from a validation study of the NIH Toolbox (N = 476) not only confirmed that the measures are reliable and valid but also yielded unique information about the structure of EF at different ages (from 3 to 85 years).[13] In general, there was good evidence of the increasing differentiation of EF from other aspects of cognitive function, which also showed increasing specialization, consistent with a characterization of neurocognitive development as interactive functional specialization.[14]

One thing the NIH Toolbox currently lacks, however, is a measure of hot EF. As Rueda and Paz-Alonso[4] note, there is an important distinction to be made between the more cool cognitive forms of EF that are prominent in cool contexts and the more hot, emotional forms of EF that play a key role in motivationally significant situations.[15] The former rely more heavily on networks involving lateral regions of *prefrontal cortex* (PFC; e.g., rostrolateral PFC) whereas the latter rely more heavily on networks involving ventral and medial regions of prefrontal cortex (e.g., orbitofrontal cortex, which is involved in the flexible re-appraisal of the affective or motivational significance of stimuli).

2. What have we learned about EF from studying the brain?

The use of the same measure of EF across the lifespan suggests that it develops most rapidly during the preschool years, but accelerates during the transition to adolescence.[9] Both periods appear to be marked by relatively rapid changes not only in behaviour but also in the structure and function of the EF-related PFC networks discussed by Knapp and Morton.[3] Although more research is required, these periods may be so-called sensitive periods of heightened sensitivity to environmental influences, including both expectable (normative) influences and those that are more unique to individuals.[16]

In general, neurocognitive development can be seen as a dynamic process of adaptation wherein neural systems are constructed (by the child) in a use-dependent fashion. Fibres connecting regions within a network (and between networks) are myelinated in a use-dependent fashion, and unused synapses are pruned. Naturally, these processes are accompanied by corresponding changes in neurocognitive function. For example, in addition to improving EF performance, training EF in early childhood produces changes in brain electrical activity measured on the scalp (i.e., the amplitude of the *N2 component*), which reflects activation of the *anterior cingulate cortex* and is reliably elicited by detection of conflict.[17,18]

This example also illustrates another important characteristic of EF: there is a dynamic interaction between top-down EF processes and bottom-up influences on EF in particular and on behaviour in general. Relatively rapid, automatic and bottom-up neurocognitive responses (e.g., the N2-indexed ACC response to conflict) appear to influence relatively slow, voluntary and top-down EF processes (e.g., by triggering the PFC activation underlying reflection[19]), and this EF, in turn, appears reciprocally to influence the more bottom-up influences (e.g., reduction in N2 amplitude). Blair's longitudinal research on EF and stress/stress reactivity[20] addresses another aspect of this dynamic interaction.

3. What are the naturally occurring influences on EF and its development, and how do they work?

While it is clear that there are genetic correlates of EF, and also that are many environmental correlates of EF,some of which are most likely causal influences, it is, as Hook, Lawson and Farah[5] point out, “difficult to disentangle the role that genetic and environmental factors play in the development of executive function.” Indeed, it may be impossible because these influences interact dynamically (over time) to yield EF phenotypes. To study this interaction, one needs to look at the bidirectional causal pathways linking genes, behaviour and aspects of the environment. For example, it will be of considerable interest to examine epigenetic changes accompanying naturally-occurring and experimentally-induced changes in EF.

4. What are the socio-demographic correlates of EF?

Both Blair[2] and Hook et al.[5] describe some of the many socio-demographic correlates of EF, which include socioeconomic status – and all the sources of variation that are captured simultaneously by this construct – but also, more precisely, specific aspects of parenting, social functioning and school achievement.

It is interesting to note that those aspects of cognitive function that are most strongly related to socioeconomic status, language and executive function, are precisely those that might be expected to be most dependent on enculturation.

Hook et al.[5] point out that research to date suggests that children from low socioeconomic status (SES) may be most likely to benefit from EF interventions. To the extent that the EF interventions provide specific opportunities that low-SES children are more likely to lack in their everyday lives (e.g., playing games that require inhibitory control, such as Simon Says), these children will be getting something that they may in fact need for the healthy or optimal development of EF to occur. Children in middle-class environments may be more likely to encounter these EF-skill-building (and playful, fun, motivating, etc.) exercises in their daily interactions with their parents, teachers, older siblings and others. Of course, they may also be more likely to encounter a safe and consistent environment, to be engaged in self-reflective, *psychologically-distanc-ing* discussions, to receive sensitive scaffolding from parents and others, and many other things that are likely to influence EF development.

It is also possible, however, that children who already have a strong foundation in EF, and are appropriately developmentally reflective and self aware, will be the children who can make the most out of any (necessarily limited) intervention. In any event, it will be important, as Blair[2] notes, to know something about the limits of EF plasticity. It would also help to know to what extent plasticity itself changes with age (e.g., in the form of sensitive periods), what variables influence plasticity, whether these influences change with age, and many other important questions. We currently know little more than that there is plasticity and that there appear to be periods of relatively rapid growth during which environmental influences play an important active role.

5. What do we know about the characteristics of interventions that improve EF?

The range of effective interventions that improve EF was comprehensively reviewed by Diamond and Lee.[21] Based in part on that review, I would suggest that effective interventions appear to have the following characteristics:

a. They tend to require goal-directed problem solving in motivationally significant contexts. The exact role of motivation in these interventions is still unclear, but learning, and likely, degree of plasticity, is generally enhanced when children are interested in something (a goal, for example), and it’s possible that there is an optimal range within which levels of interest, and motivation more generally, are most beneficial.

b. They typically require sustained self-reflective focused attention (i.e., sustained reflective reprocessing of information) on some challenge. To meet these challenges, children are called upon to slow down, reflect on the current context including relevant rules and plans, and select the appropriate rule or plan to implement.

c. They tend to involve adaptive challenges. Of course, challenges need to be adaptive in order for them to remain challenging, and for there to be something to be learned. In addition, however, degree of challenge surely interacts with motivation, and one consequence of continually challenging children is to help ensure that their motivation remains at an appropriate level.

d. They tend to involve a lot of repetition and practice. The importance of practice for skill acquisition in general is widely known, and it is now possible to observe the Hebbian processes whereby repeated practice of particular behaviours strengthens the neural pathways that underlie those behaviours.[22]

Conclusion

During the past decade, there has been considerable progress towards a more complete understanding of EF and its development during childhood. The articles[2-7] in this section provide an excellent introduction both to what has been learned so far, and to what remains to be revealed.

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