The Neurodevelopment of Executive Function Skills: Implications for Academic Achievement Gaps

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Psychology & Neuroscience, Volume 13, Issue 3, 2020,
Pages 273–298

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Econ 350, Spring 2022

- Executive function (EF) skills are a set of neurocognitive skills that support the conscious, top-down attentional control of thought, action, and emotion.

- These skills vary along a continuum of motivational significance from “hot EF” to “cool EF,” as demonstrated by lesion studies, neuroimaging studies, and research using transcranial direct stimulation (tCDS).

- Together, cool and hot EF skills make it possible to sustain attentional focus, keep goals and information in mind, refrain from responding impulsively, resist distraction, tolerate frustration, consider the consequences of different behaviors, reflect on past experiences, and plan for the future.

- In short, EF skills are essential for goal-directed problem solving, flexible adaptation to changing circumstances, effective social functioning, and intentional learning.

- Atypical development of hot and/or cool EF skills is implicated in a wide range of clinical conditions.

- The hot-cool EF dimension has proven useful in characterizing both comorbidity across diagnostic categories and heterogeneity within them.

- There is reason to believe that early perturbations of the developing brain, including exposure to adverse childhood experiences (ACEs) and stress, disrupt the development of neural systems supporting both hot and cool EF skills and confer an increased risk for general, transdiagnostic features of psychopathology.

- Research on the structure of psychopathology symptoms supports a hierarchical, bifactor model that includes a general psychopathology factor, or p factor, reflecting impairments common to all categories, as well as two (or more) specific factors, such as internalizing and externalizing.

- In a cross-sectional study with 2,395 6- to 12-year-old children, performance on a battery of EF measures was associated with risk for a latent general p factor but not the specific factors of fear, distress, and externalizing.

- The p factor is associated with a diverse set of indicators implicating difficulties with both hot EF skills (low delay discounting) and cool EF skills (low response inhibition and performance IQ), as well as direct social and emotional sequelae of these difficulties (high neuroticism and hopelessness, and low agreeableness).

- Given the hierarchical nature of both EF skills and the neural systems that support them, disruptions in any one of the lower-order networks would be expected to feed forward during development and perturb the later developing networks

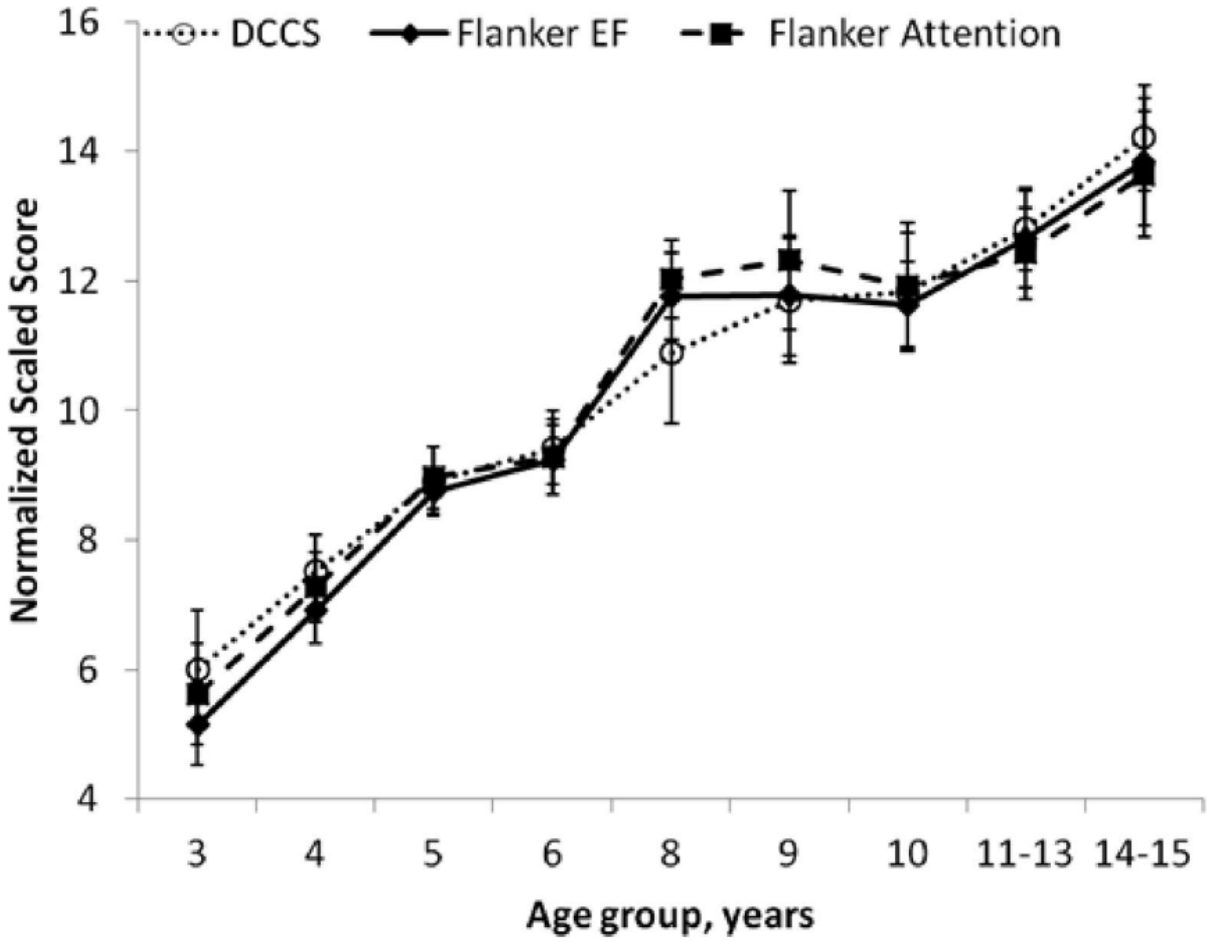
Typical Development of EF Skills in Childhood and Adolescence

- Methodological advances in the assessment of cool EF skills have resulted in standardized direct behavioral assessments that can be administered repeatedly to children as young as 2 years and across the life span.

- Examples include the National Institutes of Health (NIH) Toolbox measures of EF and the Minnesota Executive Function Scale (MEFS).

- These computer adaptive, tablet-based measures indicate that EF skills, which emerge in infancy (e.g., in the context of search for hidden objects), develop rapidly during early childhood and the transition to adolescence, and continue to improve into early adulthood (see Figure 1).

Figure 1. Performance on the NIH Toolbox Dimensional Change Card Sort Test and the Toolbox Flanker Inhibitory Control and Attention Test across age groups



Notes: Error bars are ± 2 *SE*. Also shown is the best fitting polynomial model (cubic, $R^2 = .76$), which indicates two periods of relatively rapid growth (early childhood and early adolescence).

EF, Social Understanding, and Emotion Regulation

Concurrent and Longitudinal Correlations Between EF Skills and Academic Achievement

The Role of EF Skills in Math Learning and Math Problem Solving

Neuroplasticity

- Although EF skills remain sensitive to the influence of experience across the life span, there may be periods of relatively high plasticity, during which experiential influences are particularly strong.

- As shown in Figure 1, EF skills appear to develop especially rapidly during early childhood and the transition to adolescence, indicating that underlying neural networks are adapting to correspondingly salient environmental challenges.

- Sociocultural practices such as the transitions to formal schooling, middle school, and high school, place new demands on children's EF skills, thereby growing these skills.

- In turn, growing EF skills increase children's readiness to learn (i.e., their plasticity); thus, setting up the conditions for major developmental transitions associated with these stages of life.

EF Skills Training

Transfer of Trained Skills

Enhancing Impact by Adding a Reflective, Metacognitive Component to Promote Far Transfer

Enhancing Impact Through Autonomy Supportive Practices

Enhancing Impact by Mitigating Disruptive Bottom-Up Influences Such as Stress and Anxiety

Practical Implications for Closing Achievement and Opportunity Gaps

Conclusion

- Evidence indicates that EF skills and their neural correlates become increasingly differentiated over a protracted period, but that EF skills develop relatively rapidly during the preschool and early adolescent periods. Whereas scaffolded opportunities to practice and reflect upon EF skills promotes their development, stress interferes with it.

- EF plays a central role in the development of key academic skills, and may be especially important for math.

- Correlational and training studies suggest a bidirectional relation.

- The role of EF in math can be understood in terms of EF requirements of math learning and math problem solving, as well as the abstract nature of the material and the risk of math anxiety.

- Effective interventions designed to promote EF skills have shown improvements in EF skills, evidence of far transfer, including to math, and changes in brain function.

- Interventions should address metacognitive reflection (noticing uncertainty, pausing, considering context, and monitoring) to promote far transfer of trained EF skills, and might be more effective if they target both cool and hot EF skills (e.g., by combining reflection training, EF skill training, and mindfulness).

- EF skills training can be embedded into math curricula and vice versa, and this might yield a synergistic effect.

- Doing so has the potential to address SES-related gaps in achievement and opportunity, and in particular, to raise the number of socioeconomically disadvantaged children who are proficient in math.