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Executive function: Reflection, iterative reprocessing, complexity, and the developing brain

Philip David Zelazo *

Institute of Child Development, University of Minnesota, Minneapolis, MN, USA

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ABSTRACT

Key executive function (EF) skills (cognitive flexibility, working memory, inhibitory control) are essential for goal-directed problem solving and reflective learning. This article describes executive function (EF) and its development from the perspective of the *Iterative Reprocessing (IR)* model. According to this model, reflection, or the reflective reprocessing of information prior to responding, provides a foundation for the control of attention – flexibly, over time, and selectively (i.e., cognitive flexibility, working memory, and inhibitory control). This goal-directed modulation of attention is typically verbally mediated and involves the formulation and maintenance in working memory of explicit action-oriented rules. The development of EF is made possible, in part, by increases in the efficiency of reflective reprocessing which allow for increases in the hierarchical complexity of the rules that can be used to characterize problems and select context-appropriate rules for responding. Research designed to test the model indicates that a brief intervention targeting reflection and rule use leads to improved EF and theory of mind, and produces corresponding changes in neural function.

* Institute of Child Development, University of Minnesota, 51 East River Road, Minneapolis, MN 55455-0345, USA. Fax: 612-624-6373.
E-mail address: zelazo@umn.edu.

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Introduction

This paper addresses executive function (EF), which refers to the set of self-regulatory skills involved in the conscious goal-directed modulation of thought, emotion, and action (Carlson, Zelazo, & Faja, 2013; Diamond, 2013; Jacques & Marcovitch, 2010). Interest in EF and its development during childhood is based in large part on evidence that individual differences in these skills (or proxy indicators of these skills) in childhood predict a wide range of important developmental outcomes, including school readiness in kindergarten (e.g., Blair & Razza, 2007), school performance and social competence in adolescence (e.g., Mischel, Shoda, & Rodriguez, 1989), and better physical health, higher socioeconomic status (SES), and fewer drug-related problems and criminal convictions in adulthood (Moffitt et al., 2011). The predictive power of EF is often greater than that of IQ, and long-term predictions are seen even when controlling for IQ and childhood SES.

EF skills provide an important foundation for learning and adaptation across a wide range of contexts, and children who arrive at school with well-practiced EF skills may find it easier to sit still, pay attention, remember and follow rules, and flexibly adopt new perspectives (Meuwissen & Zelazo, 2014). They may learn more easily, and as a consequence, feel more optimistic about school, and get along better with teachers and peers. It has also been argued that EF skills, as well as the reflective processes that underlie them, jointly allow for a more fully engaged, active, and reflective form of learning (Marcovitch, Jacques, Boseovski, & Zelazo, 2008), and research suggests that preschoolers with better EF skills learn more from a given amount of instruction and practice (Benson, Sabbagh, Carlson, & Zelazo, 2013; Welsh, Nix, Blair, Bierman, & Nelson, 2010). For example, Hassinger-Das, Jordan, Glutting, Irwin, and Dyson (2014) found that children with better EF skills show a larger gain in math achievement between kindergarten and first grade, especially on applied problems. Bascandziev, Zaitchik, and Carey (2015) found that 6-year-olds' EF skills predicted the extent to which training resulted in conceptual change in the construction of a vitalist biology.

The importance of EF for reflective learning and conceptual change may help explain the achievement gap between children from lower vs. higher socioeconomic (SES) backgrounds, which has widened during the past few decades along with increases in income inequality (Cahalan & Perna, 2015). Children with lower SES show lower levels of EF skill, even controlling for general cognitive skills (e.g., Farah et al., 2006; Masten et al., 2012; Mezzacappa, 2004; Noble, Norman, & Farah, 2004; Obradović, 2010). Moreover, these differences are likely to emerge early (Fernald, Marchman, & Weisleder, 2013; Tomalski et al., 2013), although they may become particularly consequential in the context of a preschool or kindergarten classroom. Teachers in these classrooms report that being able to sit still, pay attention, and remember and follow rules are more important for success than early literacy or numeracy (McClelland et al., 2007). Poor EF skills may be misinterpreted as learning disabilities, attention deficit hyperactivity disorder (ADHD), or emotional and behavioral disorders (EBDs), and may result in suspensions or expulsions (U.S. Department of Education Office for Civil Rights, 2014).

This article describes a model of self-regulation and its development, the *Iterative Reprocessing (IR)* model (e.g., Cunningham & Zelazo, 2007; Zelazo & Cunningham, 2007), that provides a framework for thinking about EF and how best to promote its healthy development. The IR model builds in part on the Levels of Consciousness model (Zelazo, 2004), the Cognitive Complexity and Control theory-Revised (Zelazo, Muller, Frye, & Marcovitch, 2003), and related theoretical models of EF (e.g., Bunge & Zelazo, 2006; Marcovitch & Zelazo, 2009). The following sections (1) define EF in terms of the IR model, (2) present an overview of the model, and (3) review recent research testing the model's prediction that EF can be improved through brief interventions targeting reflection and rule use. A full discussion of resonances with prior theoretical work (e.g., Baldwin, 1894; Craik & Lockhart, 1972; Luria, 1961; Pascual-Leone, 1970; Piaget, 1954) is beyond the scope of this article.

Defining executive function

According to the IR model, EF skills are the neurocognitive skills necessary for the top-down, goal-directed modulation of attention and behavior, and as such, they are important for intentional action, whether the goal of that action be relatively simple (e.g., stay focused on what you are reading) or more complex (e.g., pursue a career in education). As *neurocognitive* skills, EF skills are *attentional skills*,