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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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A B S T R A C T

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*, or *ways of using attention*, that depend on *specific neural circuits*, in this case involving regions in prefrontal cortex and other areas. These attentional skills serve to modulate attention in the service of a goal – flexibly, over time, and selectively – and consequently, they serve to control our behavior in corresponding ways. EF is typically measured behaviorally as three skills: cognitive flexibility, working memory, and inhibitory control (Miyake et al., 2000).

Cognitive flexibility involves thinking about something in multiple ways – for example, task switching or considering someone else's perspective on a situation. Working memory, in this context, refers to a particular cognitive function: both keeping information in mind and, usually, manipulating it in some way. Inhibitory control involves deliberately suppressing attention (or other responses) to something (e.g., ignoring a distraction or stopping an impulsive utterance). These skills, which typically work together when we are pursuing a goal, are important for characterizing problems, making inferences, and keeping goals and plans in mind, despite distractions and interference, so that they can be used, deliberately, to guide behavior.

In addition, there is behavioral evidence that EF varies along a continuum from "hot EF" to "cool EF" (Zelazo & Müller, 2002; see Peterson & Welsh, 2014, for a review). Hot EF refers to those aspects of EF that are needed in situations that are motivationally significant. Hot EF depends in part on neural networks involving more ventral and medial regions of prefrontal cortex (and pathways involving mesolimbic reward circuitry, including amygdala and striatum), and is typically assessed in tasks that require the *flexible reappraisal of whether to approach or avoid a salient stimulus*. Examples include delay of gratification (which involves avoiding a more salient immediate reward and approaching a less salient delayed reward) and the Children's Gambling Task (Kerr & Zelazo, 2004), a simplified version of the Iowa Gambling Task (Bechara et al., 1994; Noël, Brevers, & Bechara, 2013), in which the options that at first appear advantageous (higher rewards) are revealed gradually to be disadvantageous (higher rewards but even higher losses), and vice versa. Hot EF is also involved in deliberate emotion regulation.

In contrast, cool EF, assessed in relatively arbitrary or decontextualized tasks (e.g., most laboratory measures of EF, including most measures of cognitive flexibility, working memory, and inhibitory control), relies more on neural networks involving lateral parts of prefrontal cortex. A widely used measure of cool EF in childhood is the Dimensional Change Card Sort (DCCS) task (Zelazo, 2006), which is part of the National Institutes of Health Toolbox for the Assessment of Neurological and Behavioral Function (Bauer & Zelazo, 2014; Zelazo et al., 2013, 2014). In early childhood, the DCCS serves as a relatively comprehensive measure of cool EF, requiring cognitive flexibility, working memory, and inhibitory control, and capturing reliable individual differences in all three skills. By later childhood, the DCCS acts primarily as a measure of cognitive flexibility. This may be due, in part, to the experience-dependent specialization of the neural circuits underlying each aspect of cool EF (e.g., Bauer & Zelazo, 2013; Johnson, 2011).

In one version of the DCCS, presented on a tablet computer, children are shown a display with two boxes, one with a green rabbit on it and one with a purple pig (Fig. 1). They are then shown test cards with either green pigs or purple rabbits. Children are first instructed to sort by color: *All the green ones go in one box, and all the purple ones go in the other*. They sort 5 test cards in this way by dragging the virtual test cards across the touch screen, and are then told to stop sorting by color and start sorting by shape: *All the rabbits go here, and all the pigs go here*. Many typically developing preschoolers fail to keep up with these demands and instead rigidly continue to sort the cards by the first dimension, in this case, by color. They do this despite knowing the current rules and telling them to the experimenter, and this gap between knowing and being able to act on that knowledge is a classic sign of difficulty with EF.

Hot and cool EF, which typically work together in solving real-world problems, are both forms of deliberate, effortful, top-down, self-regulatory processing that depend on the prefrontal cortex, but they vary in the extent to which they require the management of motivation and emotion, including the goal-directed modulation of basic approach and avoidance motivations (Zelazo & Carlson, 2012). The distinction between hot and cool EF can be observed in children's behavior at least by 3 years of age (e.g., Hongwanishkul, Happaney, Lee, & Zelazo, 2005), although Carlson and colleagues (e.g., Bernier, Carlson, & Whipple, 2010) have found that a principal components analysis (PCA) of 26-month-olds' performance on a battery of EF measures yielded two factors, corresponding to cool EF ("conflict" tasks, such as the DCCS) and hot EF ("delay" tasks, such as delay of gratification).

Fig. 1. Stimuli in one version of the DCCS that is part of the Minnesota Executive Function Scale (MEFS; Carlson & Zelazo, 2014). Children are instructed to sort pictures first by one dimension (color) and then by another (shape). Images show the *Minnesota Executive Function Scale* by Carlson, S. M., and Zelazo, P. D., 2014, Saint Paul, MN: Reflection Sciences, LLC. Copyright © 2015 by Reflection Sciences, LLC. Reprinted with permission. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

Whereas poor hot EF in preschoolers is associated with inattentive–overactive problem behaviors, cool EF is associated with academic outcomes, including math and reading (e.g., Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Kim, Nordling, Yoon, Boldt, & Kochanska, 2013; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011). Deficits in hot EF differentiate oppositional defiant disorder/conduct disorder (ODD/CD) from attention deficit hyperactivity disorder (ADHD) in adolescence (Hobson, Scott, & Rubia, 2011), and they are differentially implicated in different forms of ADHD (e.g., Castellanos, Sonuga-Barke, Milham, & Tannock, 2006).

Most real world problems require a combination of hot and cool EF skills. Indeed, these effortful skills are invoked when there is a problem to be solved; when there is a goal and some degree of motivation to achieve that goal.

Overview of the iterative reprocessing (IR) model

The IR model characterizes deliberate self-regulation as the product of a dynamic interaction between more bottom-up (reactive) influences and more top-down (reflective) influences. Top-down influences on self-regulation are made possible by EF skills (see Fig. 2). According to the model, these EF skills correspond to various forms of goal-directed modulation of attention and, consequently, overt behavior, and they in turn are made possible by reflection – the reflective reprocessing of information via neural circuits that coordinate hierarchically arranged regions of PFC (Bunge & Zelazo, 2006). Reflection allows for the ad hoc construction of more complex representations, as measured by the hierarchical complexity of the rule systems that can be formulated and maintained in working memory (Zelazo et al., 2003). More complex rule representations, maintained in working memory, allow for more flexibility and goal-directed control in a wider range of situations, as manifested in specific EF skills. On this view, then, cognitive flexibility, working memory, and inhibitory control all depend on the iterative reprocessing of information, which permits the formulation of more complex rules that can then be used to control behavior (e.g., Cunningham & Zelazo, 2007).

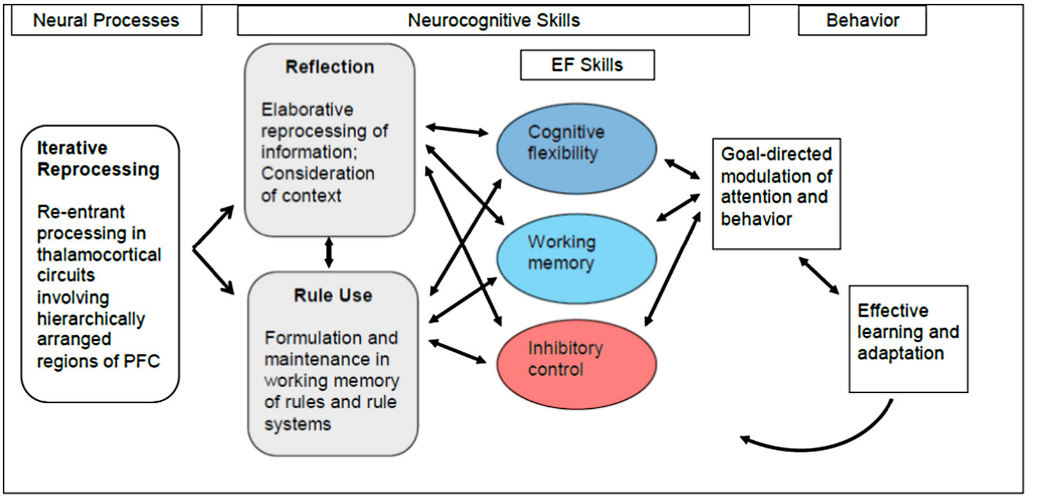

Fig. 2. Relations among levels of analysis in the Iterative Reprocessing model (e.g., Zelazo & Cunningham, 2007). EF skills are attentional skills that support (and interact with) the goal-directed modulation of attention and behavior, which is essential for effective learning and problem solving. This model further proposes that reflection, made possible by the iterative reprocessing of information via prefrontal cortex (PFC) prior to responding, provides a foundation for, and is required for rule use (inferences and action), which facilitates EF skills.

According to the model, increases in the efficiency of reflection (or the iterative reprocessing of information) occur as a result of reflecting in the context of goal-directed problem solving. Like other neurocognitive skills, reflection develops in a use-dependent way; with repeated use, the neural circuits involved in reflection become more efficient. Developmental improvements in reflection permit more efficient and effective problem construals, and allow for increases in the complexity of the rules children can formulate and keep in mind prior to responding. It is these increases in rule complexity that then more directly allow for increases in EF skills as typically measured, as cognitive flexibility, working memory, and inhibitory control. Developmentally, then, improvements in reflection are necessary (but not sufficient) for the formulation of more complex rules, or the use of language to facilitate the goal-directed control of attention, flexibly (i.e., cognitive flexibility), over time (i.e., working memory), and selectively (i.e., inhibitory control). These reflective, verbally mediated EF skills (and the neural circuitry involved) vary across hot and cool contexts (i.e., as a function of motivational significance), and become more efficient and effective as they are exercised in the context of goal-directed problem solving.

Reflection

Like EF skills, reflection is a neurocognitive skill – a way of using attention that involves specific neural circuits, and as such, it can be considered at multiple levels of analysis. At the neural level, it corresponds to the use of neural circuits involving hierarchically arranged regions of PFC that allow for the iterative reprocessing of information, so that information is fed back into the system where it can be combined with other relevant information, yielding a more elaborate construal. At the functional level of cognition, reflection is the deliberate, sustained consideration (and re-consideration) of something in the context of goal-directed problem solving. Reflection occurs when one interrupts an ongoing stream of consciousness or action, and actively considers one's situation, or construes it in a way that is experienced as "stepping back" and achieving some degree of *psychological distance* on one's experiences (Carlson & White, 2013; Dewey, 1931/1985; Sigel, 1993; Werner & Kaplan, 1963). Goal-directed reflection may be directed at an external situation (and experienced subjectively as such), but because it involves the reinterpretation of one's own construals, it is inherently directed inward, which is more obvious when we interrogate ourselves (e.g., considering our own skills, or questioning our own assumptions). In this way, reflection is inherently metacognitive and is a source of first-person information regarding developing ideas of cognition (i.e., metacognitive knowledge).

Degrees of reflection vary with degrees of construal complexity (see the section Rule Use and Cognitive Complexity) and involve neural circuits that include the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), and hierarchically arranged regions of the lateral PFC (ventrolateral PFC, dorsolateral PFC, and rostrolateral PFC). Reflection provides a necessary foundation for all forms of EF; cognitive flexibility, working memory, and inhibitory control all depend on, and indeed involve, some degree of reflection.

Information may be processed with relatively little reflection (i.e., few iterations of reprocessing), relying more on OFC than lateral PFC, as when a simple evaluation may be sufficient for the current situation. Detection of uncertainty can trigger reflection, however, in which case previously processed information from the limbic regions is additionally and concurrently processed by cortical regions. Reflection, or reprocessing, allows for more aspects of a situation to be noticed and integrated into a single construal (or interpretation), yielding a richer, more nuanced evaluation of the situation and a better appreciation of the options at one's disposal (Cunningham & Zelazo, 2007).

With more reprocessing of information, more details are perceived and integrated into one's representation of one's experience. For example, if a person is experiencing a particular stimulus (e.g., a red rabbit) in the relative absence of reflection, they may only notice a single salient feature, such as its kind. Upon further reflection, however, and with further iterations of reprocessing via neural circuits involving increasingly lateral and anterior parts of PFC, other aspects of the stimulus, such as the color and the other categories to which it belongs (e.g., red thing, animal, etc.), may become integrated into the person's conscious construal. Figure 3 illustrates how the reprocessing of information unfolds in time and allows for the construal of a stimulus within a larger context, leading to a richer

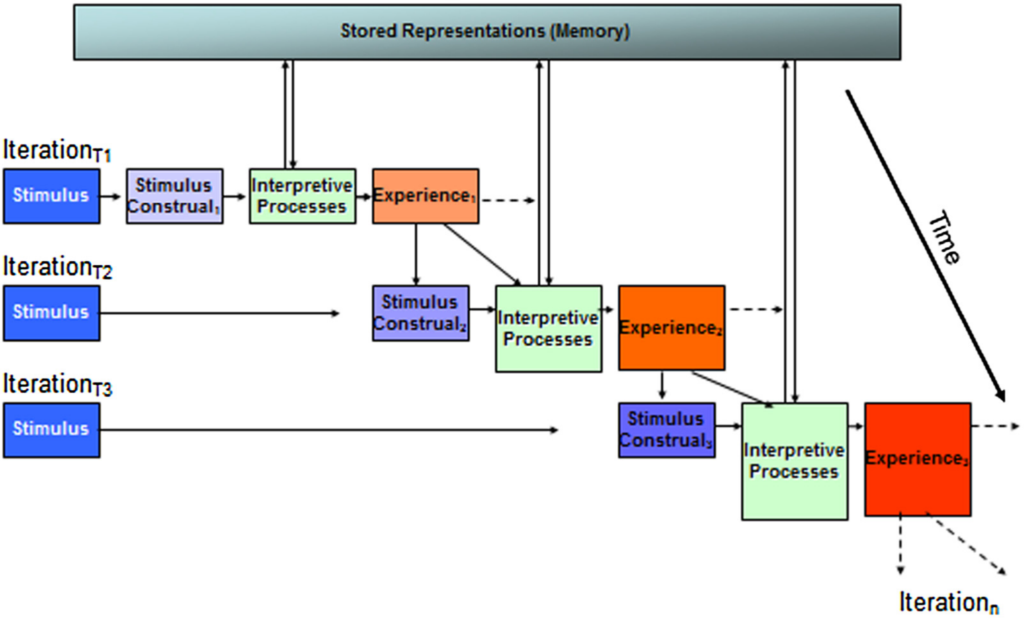

Fig. 3. Reflection unfolds in time through a series of iterations. The iterative reprocessing of information about a stimulus allows more aspects of the stimulus and of the context in which it occurs to be integrated into the experience of the stimulus. Adapted with permission from Cunningham, W. A., Zelazo, P. D., Packer, D. J., and Van Bavel, J. J. (2007). The iterative reprocessing model: A multi-level framework for attitudes and evaluation. *Social Cognition, 25*, 736–760.

qualitative experience and, importantly, to the opportunity to select and amplify attention to different aspects of a stimulus.

According to the IR model, the development of EF depends crucially on increases in the efficiency of reflection. As with all skills, reflection develops through repeated use, in the context of goal-directed problem solving, and usually in the context of parental support and scaffolding. The preschool period may be a particularly sensitive period for the development of reflection – the acquisition of reflection skills – because this is a period of rapid growth in reflection, as seen, for example, in correlated rapid improvements in EF skill and flexible perspective taking, or theory of mind (e.g., Frye et al., 1995). Carlson et al. (2013) reviewed a wide range of influences on the development of EF skills, from SES to language to attachment, and these influences on EF development might be expected to affect the development of reflection, as well.

Rule use and cognitive complexity

The goal-directed construals of a stimulus depicted in Fig. 3, where the stimulus is considered with respect to a larger context, are typically verbally mediated, and when formulated in the context of goal-directed problem solving, they are often formulated as rules that vary in complexity and flexibility. Contemporary research generally supports the seminal ideas of Vygotsky (1962) and Luria (1959, 1961) concerning the importance of verbal processes in the exercise and development of self-regulation, finding, for example, that with age children increasingly use verbalization strategically to maintain task information in mind (Karbach & Kray, 2007), and that blocking the use of inner speech disrupts cognitive control in children and adults (Emerson & Miyake, 2003; Kray, Eber, & Karbach, 2008).

According to the IR model, EF skills involve the formulation and maintenance in working memory of explicit action-oriented rules. Improvements in EF skill are made possible by increases in the efficiency and extent of reflective reprocessing, but this in turn allows for increases in the hierarchical complexity of rules that children can formulate, keep in working memory, and use (Zelazo et al., 2003). A strong case has been made for the importance of cognitive complexity, not only in research from the perspective of the IR model (e.g., Zelazo et al., 2003) but also by research on Halford's relational complexity model (e.g., Halford, Wilson, Andrews, & Phillips, 2014). One difference between these models is that relational complexity is not necessarily hierarchical, whereas hierarchical complexity is a key feature of reflection and the use of higher order rules, as captured by the IR model.

Figure 4, from Bunge and Zelazo (2006), illustrates how the ad hoc integration of knowledge structures through the formulation of higher order rules permits the flexible top-down selection of situation-appropriate rules, resulting in the inhibition of any tendency to select inappropriate rules that are elicited or primed in a bottom-up fashion. Reflection allows for a sufficiently complex construal of a problem, and the use of a higher order rule accomplishes the functions of cognitive flexibility (i.e., switching rules flexibly and appropriately) and inhibitory control (i.e., selection of an appropriate action plan entails non-selection of an inappropriate one). Reflection, or the active reprocessing of information, is also inherent in the maintenance and manipulation of information over time (i.e., working memory).

In the DCCS, for example, children need to *reflect* on the fact that there are two ways to sort the cards, *formulate a higher order rule* for selecting among rule pairs, stop sorting in the first way (*inhibitory control*), keep the current rules in mind (*working memory*), and switch to sorting by those rules (*cognitive flexibility*).

This figure also illustrates how the use of rules of differing levels of complexity maps onto networks involving increasingly anterior regions of cortex, and how reflection and higher order rule use typically increase together with a shift from more hot to more cool EF. Orbitofrontal cortex, involved in relatively hot EF, furnishes simple approach–avoidance (stimulus–reward) rules and is also involved in learning to reverse these rules. The formulation and use of more complex rules that control the application of simpler rules (e.g., if color game, then if red, then it goes here) involves the recruitment of increasingly anterior regions of the lateral prefrontal cortex into an increasingly complex, hierarchically arranged network of PFC regions. Higher levels in the hierarchy operate on the products of lower levels (see also Badre & D'Esposito, 2007; Botvinick, 2008; Christoff & Gabrieli, 2000; Goldberg & Bilder, 1987; Koechlin, Ody, & Kouneiher, 2003). As rules become more complex, they also become more abstract (i.e., abstracted away from the exigencies of a situation), and this can also be

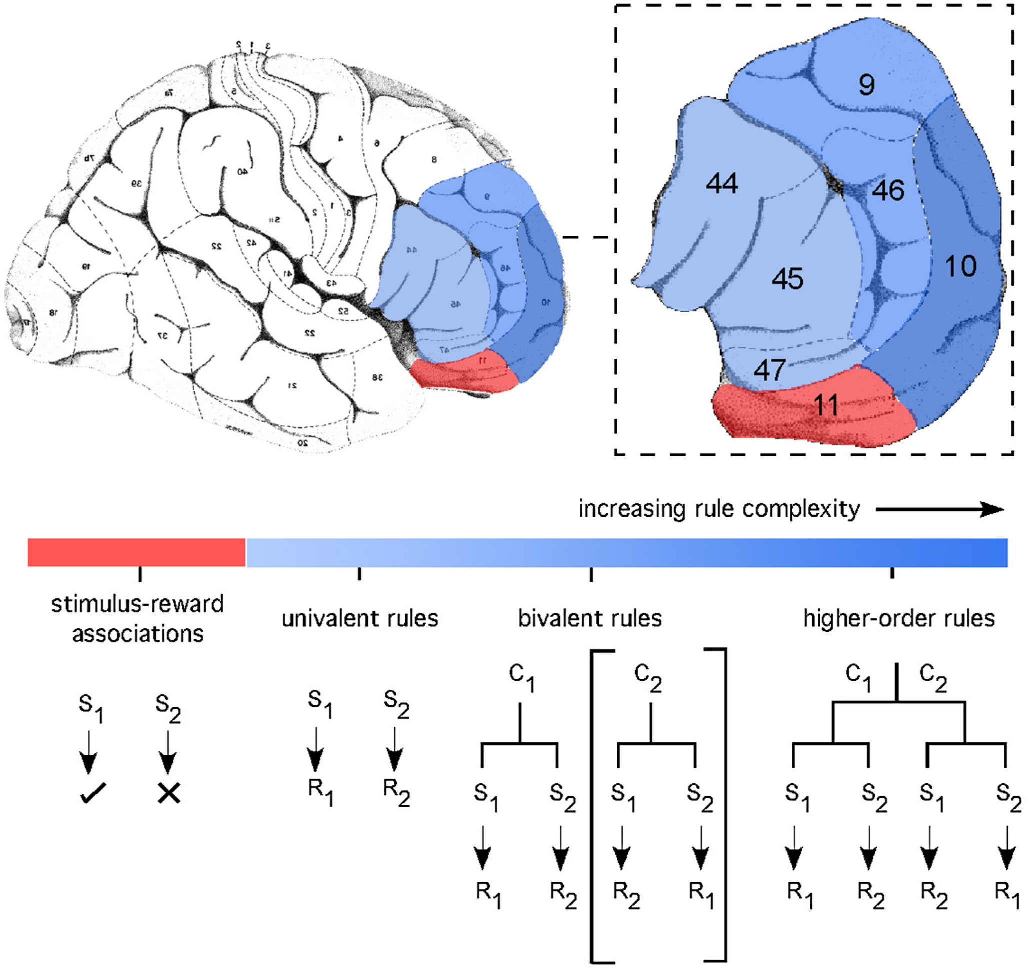

Fig. 4. A hierarchical model of rule representation in PFC. A lateral view of the human brain is depicted at the top of the figure, with regions of PFC identified by the Brodmann areas (BA) that comprise them: Orbitofrontal cortex (BA 11), ventrolateral PFC (BA 44, 45, 47), dorsolateral PFC (BA 9, 46), and rostrolateral PFC (BA 10). The PFC regions are shown in various shades of red (more hot) and blue (more cool), indicating which types of rules they represent. Rule structures are depicted below; these vary in hierarchical complexity. The formulation and maintenance in working memory of more complex rules depends on the iterative reprocessing of information through a series of levels of consciousness, which in turn depends on the recruitment of additional regions of PFC into an increasingly complex hierarchy of PFC activation. Note: S = stimulus; check = reward; cross = nonreward; R = response; C = context, or task set. Brackets indicate a bivalent rule that is currently being ignored. Reprinted with permission from: Bunge, S., and Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science, 15*, 118–121. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

viewed as a shift from hotter to cooler aspects of EF (see also Munakata, Snyder, & Chatham, 2012). In general, on this view, the development of prefrontal cortical circuitry proceeds in a bottom-up fashion that parallels well-documented age-related changes in the complexity of the rules that children can formulate, maintain in working memory, and use when solving problems. For example, research has found that even 2.5-year-olds successfully use a single arbitrary rule to sort pictures (e.g., Zelazo & Reznick, 1991), 3-year-olds can use a pair of rules, and 5-year-olds can use a hierarchical set of rules, including a higher-order rule for switching between rule pairs (e.g., Zelazo et al., 2003).

With reflection, as children integrate more features of a stimulus into their representation of it, or as they consider the current context in relation to other contexts (e.g., the previous rules), they will be better positioned to formulate more complex, nested systems of rules that accurately represent the relevant contingencies (e.g., "If I'm playing the shape game, then rabbits go with rabbits and pig go with pigs; but if I'm playing the color game, green ones go with green ones, and purple with purple"). These rule representations are verbally mediated in that they are represented internally via self-directed speech in working memory. Such complex rule representations allow for more flexibility and control in a wider range of situations than previously possible. In the absence of adequate reflection, children are limited to responding according to simple rules, particularly those that come to mind quickly. If they fail to reflect on their knowledge of the rules in relation to one another, or fail to do so quickly enough, then they will be unlikely to formulate a higher-order rule that integrates the simple rule sets before it is necessary to respond.

Detection of uncertainty: a trigger for reflection and EF

The detection of uncertainty or conflict – anything that signals a problem – can serve as a trigger to interrupt automatic processing. The IR model proposes that conflict/uncertainty detection triggers reflection, or the active, more effortful reprocessing of information, which in turn allows children to keep information actively in mind and to formulate more complex action-oriented rules that allow for greater cognitive flexibility and inhibitory control.

On the DCCS, for example, successful switching requires monitoring and detecting the conflict between the two different games being played. Once children detect a problem, they can pause, interrupting the momentum of their behavior, and reflect on the task. When they do so, they may recognize that they know two different ways of approaching the stimuli, and formulate a higher-order rule that allows them to switch between games (e.g., If it's the color game, then the green ones go here and the purple ones go there; but if it's the shape game, then the rabbits go here and the pigs go there). Consistent with this account, research indicates that the N2 component of the event related potential (ERP), generated largely by neural activity in the anterior cingulate cortex (ACC) and taken as an index of conflict detection (Botvinick, Cohen, & Carter, 2004), differentiates children who pass and fail on the DCCS (Espinet, Anderson, & Zelazo, 2012).

In particular, 3- to 4-year-old children who switched flexibly on the DCCS showed smaller amplitude N2 components of the event related potential (ERP), on both pre- and post-switch trials. N2 amplitude has consistently been associated with neural activity in the anterior cingulate cortex (ACC) and right orbitofrontal cortex in a variety of paradigms, including Go-Nogo tasks, flanker tasks, and the DCCS (e.g., Botvinick, 2007; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Lahat, Todd, Mahy, & Zelazo, 2010; Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003; Rueda et al., 2004; Waxer & Morton, 2011; Yeung & Nieuwenhuis, 2009). Lamm, Zelazo, and Lewis (2006) found that the reductions in N2 amplitude typically seen as children get older were better predicted by performance on independent measures of EF than by age per se.

The smaller N2 amplitudes in children who successfully switch on the DCCS suggest that children who pass the DCCS resolve the conflict inherent in the task more efficiently than children who fail. According to Espinet et al. (2012), children with better EF skill detected the conflict on early trials (indeed, on pre-switch trials), and this initiated reflection and the formulation and maintenance in working memory of a higher-order rule (mediated by lateral prefrontal cortical networks) that effectively resolved the conflict inherent in the stimuli and down-regulated ACC activation (cf. Botvinick et al., 2001).

Predictions of the IR model

Key aspects of the IR model have been captured in mathematical and computational models, leading to testable predictions that have since received empirical support (e.g., Marcovitch & Zelazo, 2009). This material has been reviewed elsewhere (e.g., see Zelazo, 2008; see Cunningham & Zelazo, 2010; Zelazo, 2008, for further predictions derived from this perspective). This final section highlights just two examples.

Prediction 1: labeling one's perspective on a situation should facilitate reflection, which should in turn improve cognitive flexibility

The IR model implies that EF is mediated in part by language, which is used for the formulation and use of higher-order rules. It was noted previously that articulatory suppression impairs flexible rule use, resulting not just in random errors but rather in less flexible behavior based on a simpler set of rules (e.g., Emerson & Miyake, 2003; Kray et al., 2008). In most samples, EF skill is also related to measures of language acquisition or skill (e.g., Jacques & Zelazo, 2005).

The IR model also suggests that the use of language to label one's perspective on a situation necessarily makes that perspective an explicit object of consideration, which corresponds to reflecting on that perspective. From a new, more reflective perspective it is possible to consider the initial perspective in relation to other possible perspectives. Jacques (e.g., see Jacques & Zelazo, 2005) tested this potentially counter-intuitive prediction using the Flexible Item Selection Task (FIST). On each trial of the FIST, children are shown sets of 3 items designed so one pair matches on one dimension, and a different pair matches on a different dimension (e.g., a small yellow teapot, a large yellow teapot, and a large yellow shoe). Children are first told to select one pair (i.e., Selection 1), and then asked to select a different pair (i.e., Selection 2). To respond correctly, children must construe the pivot item (i.e., the large yellow teapot) flexibly, according to both dimensions. Four-year-olds generally perform well on Selection 1 but poorly on Selection 2, indicating inflexibility (Jacques & Zelazo, 2001). According to the IR model, the 4-year-olds who show inflexibility fail to step back and reflect on their Selection 1 perspective. The IR model predicts that asking children to label their perspective on Selection 1 (e.g., "Why do those two pictures go together?") should cause them to make their Selection 1 perspective an object of consideration, thereby stepping outside of that perspective, making it possible to adopt a different perspective on Selection 2. Alternatively, one might propose that labeling the Selection 1 perspective would reinforce attention to that perspective, making it more salient and possibly harder to inhibit. In fact, labeling Selection 1 was found in a series of experiments to facilitate flexibility, and this was true whether children provided the label themselves or whether the experimenter generated it for them. These results suggest that labeling facilitates children's reflection on their initial construal of the stimuli.

Prediction 2: training reflection and rule use should improve EF skill

Research in developmental neuroscience suggests that neurocognitive development can be seen as a dynamic process of adaptation wherein neural systems are constructed in a largely use-dependent fashion. When we use our brains in particular ways, the neural circuits upon which we rely become more efficient. Fibers connecting regions within a network (and between networks) are myelinated when used, and unused synapses are pruned. The human brain is an inherently plastic organ, continually adapting to its environment, but there are periods of relatively high plasticity (often called "sensitive periods") when particular regions of the brain and their corresponding functions are especially susceptible to environmental influences. These periods typically correspond to times of rapid growth in those regions and functions, when relevant neural regions are adapting especially rapidly to structure inherent in the environment (Huttenlocher, 2002). Because EF undergoes a particularly rapid transformation during early childhood (Zelazo et al., 2013), the preschool period may be a window of opportunity for the cultivation of fundamental EF skills via well-timed, targeted scaffolding and support.

The IR model predicts that scaffolded practice reflecting and formulating a higher order rule should lead to the more efficient use of these skills in the future. According to the model, reflection and rule use are the most promising targets of interventions designed to improve EF. In fact, interventions that have been shown to improve EF skills tend to require children to pause momentarily and reflect before responding. They also generally involve repeated practice; and they get progressively more challenging as children improve. Diamond and Lee (2011) reviewed a wide variety of interventions targeting EF and found considerable evidence that EF skills can be improved through practice and the exercise of those skills in a wide variety of contexts, including computer-based games, aerobics, martial arts, yoga, mindfulness, and school curricula. This evidence has helped clarify the conditions that support the healthy development of EF, and sheds light on the mechanisms that underlie developmental change.

Espinet et al. (2013) used an experimental design to test specific predictions derived from the IR model. Children who failed the DCCS were given a different version of the DCCS (with different shapes and colors) and taught to pause before responding, reflect on the hierarchical nature of the task, and formulate higher-order rules for responding flexibly: “In the color game, then if it’s a green pig, then it goes here; but in the shape game that same green pig goes there.” Compared to children who received only *minimal yes/no feedback* (without practice in reflection) and to children who received *mere DCCS practice with no feedback* at all, children who received *reflection training* showed significant improvements in performance on a subsequent administration of the DCCS. Improvements were also seen on other tasks, including a measure of flexible perspective taking (a false belief task), and these behavioral changes were accompanied by predictable changes in children’s brain activity, specifically a reduction in the amplitude of the N2 component in the ERP (see previous section on Detection of Uncertainty). This suggests that reflection training leads not only to improvements in children’s EF but also to changes in the amplitude of their N2 responses so that those responses resemble those of children who pass (Espinet et al., 2013). In terms of the IR model, reflection training facilitated reflection, which led to the more efficient and effective formulation and maintenance in working memory of a higher-order rule (mediated by lateral prefrontal cortical networks), and this in turn resolved the conflict inherent in the stimuli and down-regulated ACC activation (cf. Botvinick et al., 2001).

This example illustrates another important characteristic of the IR model: the dynamic interaction between top-down influences on behavior, such as EF skills, and a wide range of more bottom-up influences on behavior. Relatively rapid, automatic, bottom-up neurocognitive responses (e.g., the N2-indexed ACC response to conflict) appear to influence relatively slow, voluntary, top-down EF processes (e.g., by triggering the PFC activation underlying reflection), and these processes, in turn, appear reciprocally to influence the more bottom-up influences (e.g., reduction in N2 amplitude).

This research also suggests that it is possible to train high-level skills like reflection and cognitive flexibility, with corresponding neural changes that may reflect myelination, dendritic thickening, and synaptic pruning. A consequence is that trained networks become more efficient, so reflection and executive function occur more automatically and more quickly, providing more time for thoughtful reflection prior to overt action or to decision making.

Conclusion

EF is increasingly recognized as a foundational skill that makes it possible for children to adapt more effectively to the challenges they face. During the past decade, there has been considerable progress toward a more complete understanding of EF and its development during childhood. Research is revealing the way in which experience shapes the neural circuitry underlying EF, and interventions targeting reflection have the potential to help children at risk for a wide range of difficulties. Successful interventions provide children with opportunities to reflect on situations prior to acting, and there is evidence that the processes involved in reflection become more efficient with practice.

The IR model provides a theoretical framework with which to understand EF skills at multiple levels of analysis (cognitive, neural, emotional, phenomenological). Future research may usefully be directed at understanding more precisely the role that EF plays in learning, but the research reviewed suggests that EF skills play an important role in allowing children more effectively to learn from experience, and also that these skills may be cultivated during childhood by interventions targeting reflection and rule use.

References

Badre, D., & D’Esposito, M. (2007). Functional magnetic resonance imaging evidence for a hierarchical organization of the prefrontal cortex. *Journal of Cognitive Neuroscience*, *19*, 2082–2099.

Baldwin, J. M. (1894). Imitation: A chapter in the natural history of consciousness. *Mind; a Quarterly Review of Psychology and Philosophy*, *3*, 25–55.

Bascandziev, I., Zaitchik, D., & Carey, S. (2015). *Exploring the relationship between executive functions and the construction of a vitalist theory of biology in young children*. Manuscript under review.

Bauer, P. J., & Zelazo, P. D. (2013). NIH Toolbox Cognition Battery (CB): Summary, conclusions, and implications for cognitive development. In P. D. Zelazo & P. J. Bauer (Eds.), National Institutes of Health Toolbox – Cognition Battery (NIH Toolbox CB): Validation for children between 3 and 15 years. *Monographs of the Society for Research in Child Development*, *78*(4), 143–146.

Bauer, P. J., & Zelazo, P. D. (2014). The National Institutes of Health Toolbox for the Assessment of Neurological and Behavioral Function: A tool for developmental science. *Child Development Perspectives*, *8*, 119–124.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7–15.
Benson, J., Sabbagh, M., Carlson, S. M., & Zelazo, P. D. (2013). Individual differences in executive functioning predict preschoolers' improvement from theory-of-mind training. *Developmental Psychology*, *49*, 1615–1627.
Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: Early parenting precursors of young children's executive functioning. *Child Development*, *81*(1), 326–339.
Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–680.
Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 356–366.
Botvinick, M. M. (2008). Hierarchical models of behavior and prefrontal function. *Trends in Cognitive Science*, *12*, 201–208.
Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.
Botvinick, M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Sciences*, *8*, 539–546.
Brock, L. L., Rimm-Kaufman, S. E., Nathanson, L., & Grimm, K. J. (2009). The contributions of 'hot' and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. *Early Childhood Research Quarterly*, *24*(3), 337–349.
Bunge, S., & Zelazo, P. D. (2006). A brain-based account of the development of rule use in childhood. *Current Directions in Psychological Science*, *15*, 118–121.
Cahalan, M., & Perna, L. W. (2015). *Indicators of higher education equity in the United States: 45-year trend report*. Washington, DC: The Pell Institute and Penn AHEAD.
Carlson, S. M., & White, R. E. (2013). Executive function, pretend play, and imagination. In M. Taylor (Ed.), *Oxford handbook of imagination*. New York: Oxford University Press.
Carlson, S. M., & Zelazo, P. D. (2014). *Minnesota executive function scale*. Saint Paul, MN: Reflection Sciences, LLC.
Carlson, S. M., Zelazo, P. D., & Faja, S. (2013). Executive function. In P. D. Zelazo (Ed.), *Oxford handbook of developmental psychology, Vol. 1: Body and mind* (pp. 706–743). New York: Oxford University Press.
Castellanos, F. X., Sonuga-Barke, E. J. S., Milham, M. P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences*, *10*(3), 117–123.
Christoff, K., & Gabrieli, J. D. (2000). The frontopolar cortex and human cognition: Evidence for a rostrocaudal hierarchical organization within the human prefrontal cortex. *Psychobiology*, *28*, 168–186.
Craik, F., & Lockhart, R. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*, 671–684.
Cunningham, W. A., & Zelazo, P. D. (2010). The development of iterative reprocessing: Implications for affect and its regulation. In P. D. Zelazo, M. Chandler, & E. A. Crone (Eds.), *Developmental social cognitive neuroscience* (pp. 81–98). Mahwah, NJ: Lawrence Erlbaum Associates.
Cunningham, W. A., Zelazo, P. D., Packer, D. J., & Van Bavel, J. J. (2007). The iterative reprocessing model: A multi-level framework for attitudes and evaluation. *Social Cognition*, *25*, 736–760.
Cunningham, W., & Zelazo, P. D. (2007). Attitudes and evaluation: A social cognitive neuroscience perspective. *Trends in Cognitive Sciences*, *11*, 97–104.
Dewey, J. (1931/1985). Context and thought. In J. A. Boydston & A. Sharpe (Eds.), *John Dewey: The later works, 1925–1953* (Vol. 6, pp. 3–21). Carbondale, IL: Southern Illinois University Press.
Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*, 135–168.
Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*, 959–964.
Emerson, M. J., & Miyake, A. (2003). The role of inner speech in task switching: A dual-task investigation. *Journal of Memory and Language*, *48*, 148–168. doi:10.1016/S0749-596X(02)00511-9.
Espinet, S. D., Anderson, J. E., & Zelazo, P. D. (2012). N2 amplitude as a neural marker of executive function in young children: An ERP study of children who switch versus perseverate on the Dimensional Change Card Sort. *Developmental Cognitive Neuroscience*, *2*, S49–S58.
Espinet, S. D., Anderson, J. E., & Zelazo, P. D. (2013). Reflection training improves executive function in preschool children: Behavioral and neural effects. *Developmental Cognitive Neuroscience*, *4*, 3–15. doi:10.1016/j.dcn.2012.11.009.
Farah, M. J., Shera, D. M., Savage, J. H., Betancourt, L., Giannetta, J. M., Brodsky, N. L., et al. (2006). Childhood poverty: Specific associations with neurocognitive development. *Brain Research*, *1110*, 166–174.
Fernald, A., Marchman, V. A., & Weisleder, A. (2013). SES differences in language processing skill and vocabulary are evident at 18 months. *Developmental Science*, *16*, 234–248.
Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, *10*, 483–527.
Goldberg, E., & Bilder, R. M., Jr. (1987). The frontal lobes and hierarchical organization of cognitive control. In E. Perecman (Ed.), *The frontal lobes revisited* (pp. 159–187). New York: The IRBN Press.
Halford, G. S., Wilson, W. S., Andrews, G., & Phillips, S. (2014). *Categorizing cognition: Toward conceptual coherence in the foundations of psychology*. Cambridge, MA: MIT Press.
Hassinger-Das, B., Jordan, N. C., Glutting, J., Irwin, C., & Dyson, N. (2014). Domain-general mediators of the relation between kindergarten number sense and first-grade mathematics achievement. *Journal of Experimental Child Psychology*, *118*, 78–92.
Hobson, C. W., Scott, S., & Rubia, K. (2011). Investigation of cool and hot executive function in ODD/CD independently of ADHD. *Journal of Child Psychology and Psychiatry*, *52*(10), 1035–1043.
Hongwanishkul, D., Happaney, K. R., Lee, W., & Zelazo, P. D. (2005). Hot and cool executive function: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*, 617–644.
Huttenlocher, P. R. (2002). *Neural plasticity: The effects of environment on the development of the cerebral cortex*. Cambridge, MA: Harvard University Press.

Jacques, S., & Marcovitch, S. (2010). Executive function. In W. Overton (Ed.), *Handbook of lifespan development* (pp. 431–466). New York: Wiley.
Jacques, S., & Zelazo, P. D. (2001). The Flexible Item Selection Task (FIST): A measure of executive function in preschoolers. *Developmental Neuropsychology*, *20*, 573–591.
Jacques, S., & Zelazo, P. D. (2005). Language and the development of cognitive flexibility: Implications for theory of mind. In J. W. Astington & J. A. Baird (Eds.), *Why language matters for theory of mind* (pp. 144–162). New York: Oxford University Press.
Johnson, M. H. (2011). Interactive specialization: A domain-general framework for human functional brain development? *Developmental Cognitive Neuroscience*, *1*, 7–21.
Karbach, J., & Kray, J. (2007). Developmental changes in switching between mental task sets: The influence of verbal labeling in childhood. *Journal of Cognition and Development*, *8*, 205–236. doi:10.1080/15248370701202430.
Kerr, A., & Zelazo, P. D. (2004). Development of "hot" executive function: The Children's Gambling Task. *Brain and Cognition*, *55*, 148–157.
Kim, S., Nordling, J. K., Yoon, J. E., Boldt, L. J., & Kochanska, G. (2013). Effortful control in "hot" and "cool" tasks differentially predicts children's behavior problems and academic performance. *Journal of Abnormal Child Psychology*, *41*(1), 43–56.
Koechlin, E., Ody, C., & Kouneiher, F. (2003). The architecture of cognitive control in the human prefrontal cortex. *Science*, *302*(5648), 1181–1185.
Kray, J., Eber, J., & Karbach, J. (2008). Verbal self-instructions in task switching: A compensatory tool for action-control deficits in childhood and old age? *Developmental Science*, *11*, 223–236. doi:10.1111/j.1467-7687.2008.00673.
Lahat, A., Todd, R. M., Mahy, C. E. V., & Zelazo, P. D. (2010). Neurophysiological correlates of executive function: A comparison of European-Canadian and Chinese-Canadian 5-year-old children. *Frontiers in Human Neuroscience*, *3*(72), 1–10.
Lamm, C., Zelazo, P. D., & Lewis, M. D. (2006). Neural correlates of cognitive control in childhood and adolescence: Disentangling the contributions of age and executive function. *Neuropsychologia*, *44*, 2139–2148.
Luria, A. R. (1959). The directive function of speech in development and dissolution. *Word*, *15*, 341–352.
Luria, A. R. (1961). J. Tizard (Ed.), *The role of speech in the regulation of normal and abnormal behavior*. New York: Liveright Publishing Corporation.
Marcovitch, S., Jacques, S., Boseovski, J. J., & Zelazo, P. D. (2008). Self-reflection and the cognitive control of behavior: Implications for learning. *Mind, Brain, and Education*, *2*, 136–141.
Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the emergence and early development of executive function (Target article with commentaries). *Developmental Science*, *12*, 1–18.
Masten, A. S., Herbers, J. E., Desjardins, C. D., Cutuli, J. J., McCormick, C. M., Sapienza, J. K., et al. (2012). Executive function skills and school success in young children experiencing homelessness. *Educational Researcher*, *41*, 373–384.
McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*(4), 947–959.
Meuwissen, A. S., & Zelazo, P. D. (2014). Hot and cool executive function: Foundations for learning and healthy development. *Zero to Three*, *35*, 18–23.
Mezzacappa, E. (2004). Alerting, orienting, and executive attention: developmental properties and sociodemographic correlates in an epidemiological sample of young, urban children. *Child Development*, *75*, 1373–1386.
Mischel, W., Shoda, Y., & Rodriguez, M. L. (1989). Delay of gratification in children. *Science*, *244*, 933–938.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.
Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., et al. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America*, *108*(7), 2693–2698.
Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current Directions in Psychological Science*, *21*(2), 71–77. doi:10.1177/0963721412436807.
Nieuwenhuis, S., Yeung, N., Van Den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience*, *3*(1), 17–26.
Noble, K. G., Norman, M. F., & Farah, M. J. (2004). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, *8*(1), 74–87.
Noël, X., Brevers, D., & Bechara, A. (2013). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology*, *23*, 632–638.
Obradović, J. (2010). Effortful control and adaptive functioning of homeless children: Variable- and person-focused analyses. *Journal of Applied Developmental Psychology*, *31*, 109–117.
Pascual-Leone, J. (1970). A mathematical model for the transition rule in Piaget's developmental stages. *Acta Psychologia*, *32*, 301–345.
Peterson, E., & Welsh, M. C. (2014). The development of hot and cool executive functions in childhood and adolescence: Are we getting warmer? In S. Goldstein & J. A. Naglieri (Eds.), *Handbook of executive functioning*. New York: Springer. doi:10.1007/978-1-4614-8106-5_4.
Piaget, J. (1954). *The construction of reality in the child*. New York: Basic.
Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*(8), 1029–1040.
Sigel, I. (1993). The centrality of a distancing model for the development of representational competence. In R. R. Cocking & K. A. Renninger (Eds.), *The development and meaning of psychological distance* (pp. 91–107). Hillsdale, NJ: Erlbaum.
Tomalski, P., Moore, D. G., Ribeiro, H., Axelsson, E., Murphy, E., Karmiloff-Smith, A., et al. (2013). Socio-economic status and functional brain development – Associations in early infancy. *Developmental Science*, *16*(5), 676–687.
U.S. Department of Education Office for Civil Rights (2014). *Civil rights data collection: Data snapshot (early childhood)*. March 21, 2014.
Vygotsky, L. S. (1962). *Thought and language* (E. Hanfmann & G. Vakar, Trans.). Cambridge, MA: MIT Press. (Original work published 1934).

Waxer, M., & Morton, J. B. (2011). Multiple processes underlying dimensional change card sort performance: A developmental electrophysiological investigation. *Journal of Cognitive Neuroscience*, *23*(11), 3267–3279.
Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, *102*, 43–53.
Werner, H., & Kaplan, B. (1963). *Symbol formation: An organismic developmental approach to language and the expression of thought*. New York: John Wiley.
Willoughby, M., Kupersmidt, J., Voegler-Lee, M., & Bryant, D. (2011). Contributions of hot and cool self-regulation to preschool disruptive behavior and academic achievement. *Developmental Neuropsychology*, *36*(2), 162–180.
Yeung, N., & Nieuwenhuis, S. (2009). Dissociating response conflict and error likelihood in anterior cingulate cortex. *The Journal of Neuroscience*, *29*(46), 14506–14510.
Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences*, *8*, 12–17.
Zelazo, P. D. (2006). The Dimensional Change Card Sort: A method of assessing executive function in children. *Nature Protocols*, *1*, 297–301.
Zelazo, P. D. (2008). A theoretical account of the development of rule use over childhood. In S. A. Bunge & J. D. Wallis (Eds.), *Perspectives on rule-guided behavior* (pp. 441–476). New York: Oxford University Press.
Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., Conway, K. P., et al. (2014). NIH Toolbox Cognition Battery (CB): Validation of executive function measures in adults. *Journal of the International Neuropsychological Society*, *20*(06), 620–629.
Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). NIH Toolbox Cognition Battery (CB): Measuring executive function and attention. In P. D. Zelazo & P. J. Bauer (Eds.), National Institutes of Health Toolbox – Cognition Battery (NIH Toolbox CB): Validation for children between 3 and 15 years. *Monographs of the Society for Research in Child Development*, *78*(4), 16–33.
Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*, 354–360.
Zelazo, P. D., & Cunningham, W. A. (2007). Executive function: Mechanisms underlying emotion regulation. In J. J. Gross (Ed.), *Handbook of emotion regulation* (pp. 135–158). New York: Guilford Press.
Zelazo, P. D., Muller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood. *Monographs of the Society for Research in Child Development*, *68*(3), Serial No. 274.
Zelazo, P. D., & Müller, U. (2002). Executive functions in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445–469). Oxford: Blackwell.
Zelazo, P. D., & Reznick, J. S. (1991). Age related asynchrony of knowledge and action. *Child Development*, *62*, 719–735.