Revista Argentina de Ciencias del Comportamiento

ISSN 1852-4206

Marzo 2015, Vol. 7, N°1, 53-59

revistas.unc.edu.ar/index.php/racc

Reflection and Executive Function: Foundations for Learning and Healthy Development

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Review Article

Abstract

Executive function (EF) refers to the neurocognitive processes involved in the deliberate, goal-directed modulation of thought, action, and emotion. Individual differences in EF measured in childhood predict key developmental outcomes, and interventions designed to foster the healthy development of EF have the potential to help children at risk for a wide range of difficulties. This article briefly describes a theoretical model of EF and its development, the Iterative Reprocessing model, that spans levels of analysis and characterizes self-regulation as the product of a dynamic interaction between top-down (reflective) and bottom-up (reactive) influences.

Key Words:
Hot executive function; Neuroplasticity; Rule use; Reflection; Iterative Reprocessing (IR) model; Interventions

Resumen

Reflexión y funciones ejecutivas: Bases para el aprendizaje y el desarrollo saludable. Las funciones ejecutivas (FE) hacen referencia a los procesos neurocognitivos involucrados en la modulación intencional del pensamiento, las acciones y las emociones dirigidos a fines. Las diferencias individuales en las EF evaluadas durante la niñez predicen aspectos clave de su desarrollo. Asimismo, las intervenciones diseñadas para fomentar el desarrollo adecuado de las FE tienen el potencial de ayudar a niños con diferentes tipos de riesgo debido a una amplia gama de dificultades. Este artículo describe brevemente un modelo teórico de FE y su desarrollo -el modelo de Reprocesamiento Iterativo, que abarca diferentes niveles de análisis y que caracteriza a la autorregulación como el producto de una interacción dinámica entre influencias de tipo top-down (reflexivas) y bottom-up (reactivas).

Palabras Claves:
Funciones ejecutivas calientes; neuroplasticidad; uso de reglas; reflexión; modelo de reprocesamiento iterativo (IR); intervenciones.

Received on February 13, 2015; Review received on January, 24th, 2015; Approved on March, 3th, 2015.

1. Introduction

This paper addresses executive function (EF), which refers to the set of self-regulatory skills involved in the goal-directed modulation of thought, emotion, and action. EF and its development in childhood have generated an immense amount of interest in the past decade (Carlson, Zelazo, & Faja, 2013). One reason for the interest is research that indicates that individual differences in EF measured in childhood predict a wide range of important developmental outcomes, including school readiness (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 goals of this paper are to: (1) describe the specific skills involved in EF and how these skills are measured, (2) summarize a process model of the neurocognitive mechanisms involved in EF, and (3) review how EF skills can be improved, with a specific focus on reflection.

1.1. *Executive Function Skills*

EF is typically measured by assessing three skills that are important for behavioral regulation: (1) *cognitive flexibility*, shifting between task sets or between different ways of construing a situation; (2) *inhibitory control*, actively suppressing attention to

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Cite this article as: Almy, B.K. & Zelazo, P.D. (2015). Reflection and Executive Function: Foundations for Learning and Healthy Development. *Revista Argentina de Ciencias del Comportamiento*, *7*(1), 53-59.

distracting information or withholding a prepotent response; and (3) *working memory*, maintaining information consciously in mind and using it to guide goal-directed behavior (Miyake et al. 2000). In addition, research has supported a distinction between what are called “hot EF” and “cool EF” (Zelazo & Mueller, 2002). Hot EF refers to those aspects of EF that are needed in situations that are motivationally significant—that are personally meaningful. These situations could include waiting for an eagerly anticipated present, taking a high-pressure test in school, or talking to a boss about a possible promotion. Hot EF depends in part on neural networks involving ventral and medial regions of prefrontal cortex (PFC), and is typically assessed in tasks that require the flexible reappraisal of whether to approach or avoid a salient stimulus. In contrast, cool EF, assessed in relatively arbitrary or decontextualized contexts (e.g., most laboratory measures of EF, such as the dimensional change card sort (DCCS; Zelazo, 2006)), relies more on neural networks involving lateral parts of PFC. Hot and cool EF, which typically work together in solving real-world problems, are both forms of effortful, top-down, self-regulatory processing that depend on PFC, but they vary in the extent to which they require the management of motivation and emotion, including the modulation of basic approach and avoidance motivations (Zelazo & Carlson, 2012).

1.2. *Development of EF Skills*

Developmentally, cool EF can be considered a unitary construct that becomes increasingly differentiated with age. Several studies of task-appropriate measures of cool EF for preschool children demonstrate that a one-factor model best represents EF (Wiebe, Espy, & Charack, 2008; Wiebe et al., 2011). Around middle childhood, two factors can be seen: working memory and cognitive flexibility (Huizinga, Dolan, & van der Molen, 2006). With an older adolescent sample, there was statistical support for the full tripartite model of cognitive flexibility, working memory, and inhibitory control (Friedman et al., 2008). In the above studies, the researchers did not include hot EF in their statistical models, but other research has found evidence of the early appearance of a distinction between hot and cool EF. For example, Carlson and colleagues (Bernier, Carlson & Whipple, 2010; Carlson, White, & Davis-Unger, 2014) have found that preschool age children who do well on measures of cool EF (“conflict” tasks, such as the DCCS) do not necessarily do well on hot EF (“delay” tasks, such as delay of gratification). Hongwanishkul, Happaney, Lee, and Zelazo (2005) also reported low correlations between hot and cool EF in preschool age children, and whereas hot EF in preschoolers is associated with inattentive-overactive problem behaviors, cool EF is associated with academic outcomes (Kim, Nordling, Yoon, Boldt, & Kochanska, 2013; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011).

A widely used measure of cool EF in childhood and across the lifespan is the DCCS task (Zelazo, 2006), which is part of the National Institutes of Health Toolbox for the Assessment of Neurological and Behavioral Function (Zelazo et al., 2013; Zelazo et al., 2014). In early childhood, it serves as a comprehensive measure of cool EF, requiring cognitive flexibility, working memory, and inhibitory control. By later childhood, it acts primarily as a measure of cognitive flexibility.

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 (Figure 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 five 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. Now, children need to reflect on the fact that there are two ways to sort the cards, stop sorting in the first way, keep the current rules in mind, and switch to sorting by those rules. 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 shape. 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.

Figure 1. Top: 3-year-old boy completing a version of the DCCS, as part of the Minnesota Executive Function Scale (MEFS; Carlson & Zelazo, 2014). Children are instructed to sort pictures first by one dimension (shape) and then by another (color). Bottom: Images show the Minnesota Executive Function Scale by S. M. Carlson and P. D. Zelazo, 2014, Saint Paul, MN: Reflection Sciences, LLC. Copyright © 2015 by Reflection Sciences, LLC. Reprinted with permission.

Research using the MEFS and the NIH Toolbox measures of EF have helped characterize the development of cool EF across the lifespan, using the same measures from ages 2 to 85 years (Carlson & Zelazo; 2014; Zelazo et al., 2013; Zelazo et al., 2014). Cool EF skills develop rapidly during the preschool years, from about 3 and 6 years of age. They continue to improve at a slower rate until early adolescence, when there is another period of rapid improvement, and then they again improve more gradually until reaching a peak in the early 20s. Hot and cool EF seem to follow different developmental trajectories, however, with hot EF lagging behind and continuing to develop later. One study with children ages 8 to 15 years found that for cool EF, there was a transition toward more adult-like performance at around 10 years of age, but for hot EF, this transition did not occur until around 14 years (Prencipe et al., 2011).

1.3. *Reflection and the Iterative Reprocessing Model*

According to the Iterative Reprocessing (IR) model (Cunningham & Zelazo, 2007; Zelazo & Cunningham, 2007), which builds on the Cognitive Complexity and Control theory-Revised (Zelazo, Müller, Frye, & Marcovitch, 2003) and related theoretical models of EF (e.g., Marcovitch & Zelazo, 2009; Zelazo, 2004), the development of EF is made possible by increases in the reflective reprocessing of information via neural circuits that coordinate hierarchically arranged regions of PFC (Bunge & Zelazo, 2006). This coordination permits increases in the hierarchical complexity of rules that can be formulated and maintained in working memory (Zelazo et al., 2003). More complex rule representations allow for more flexibility and control in a wider range of situations than previously possible.

A key trigger for reflection is the detection of uncertainty or conflict. More generally, anything that signals a problem—the need to proceed deliberately, in a top-down, controlled fashion—can serve as a trigger to interrupt automatic processing. The IR model proposes that conflict/uncertainty detection triggers reflection, or the active 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 described earlier, 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 red ones go here and the blue ones go there; but if it's the shape game, then the rabbits go here and the boats go there). Consistent with this account, research indicates that the N2 component of the event related potential (ERP), generated largely by neural activity in 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, and that reflection training leads not only to improvements in children's EF, but also changes the amplitude of their N2 responses so that they resemble those of children who pass (Espinet, Anderson, & Zelazo, 2012; Espinet, Anderson, & Zelazo, 2013), as described later.

A key feature of the IR model is that it captures the dynamic interaction between more bottom-up (e.g., limbic) and more top-down (e.g., cortical) influences on information processing and goal-directed behavior. Limbic regions interact with cortical areas of the brain, including orbitofrontal cortex (OFC), the ACC, and the hierarchically arranged regions of the lateral PFC (ventrolateral PFC, dorsolateral PFC, and rostrolateral PFC). Information may be processed with relatively little reflection (i.e., few iterations of reprocessing), relying more on limbic regions, as when a simple evaluation may be sufficient for the current situation. Detection of uncertainty can trigger reflection, in which case previously processed information from the limbic regions is additionally and concurrently processed by cortical regions. Reprocessing allows for more aspects of a situation to be noticed and integrated into a construal (or interpretation), yielding a richer, more nuanced evaluation of the situation and an appreciation of the options at one's disposal.

As children exercise their EF skills, networks in PFC become more efficient (e.g., through synaptic pruning). In particular, there is a close correspondence between the development of lateral PFC and increases in rule use: understanding, formulating, and following rules in order to regulate behavior (Bunge & Zelazo, 2006). On the DCCS and other measures of rules use, performance improves markedly in the preschool period. With age and experience, children show increases in the complexity of the rules that they can formulate and use. Relatively simple rules, (e.g., stimulus-response associations and their reversal) appear relatively early in development and are associated more with OFC. Over the course of the preschool years, children are able to use increasingly complex rules that depend on more complex neural networks integrating first ventrolateral, then dorsolateral, and finally, rostrolateral PFC. 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 (e.g., shape rules in the DCCS), 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., 2013)

1.4 *Implications*

EF skills provide a foundation for learning and adaptation: They make it possible to sustain attention, keep goals and information in mind, refrain from responding immediately, resist distraction, tolerate frustration, consider the consequences of different behaviors, reflect on past experiences, and plan for the future (Carlson et al., 2013). They allow for a more fully present, active, and reflective form of learning (Marcovitch, Jacques, Boseovski, & Zelazo ,2008).

In early childhood, too many children are showing up without the skills needed to learn in a classroom context. Kindergarten teachers recognize this, and report that being able to sit still, pay attention, and remember and follow rules are more important for success in their classrooms than is early literacy or numeracy (McClelland et al., 2007). Of course, it is relatively easy to teach traditional academic content (reading, writing, and arithmetic) to children who can control their behavior in the classroom—children who pay attention, are cognitively flexible, and reflect on what they are learning, so the strong link between EF and school success is no surprise. In a recent study, we found that children with better EF skills actually learn more from a given amount of instruction and practice (Benson, Sabbagh, Carlson, & Zelazo 2013). They also show larger gains in math achievement between kindergarten and first grade (Hassinger-Das, Jordan, Glutting, Irwin, & Dyson, 2014).

Fortunately, research indicates that EF skills can be trained, and it has helped clarify the conditions that support the healthy development of EF. Diamond and Lee (2011) reviewed a wide variety of interventions targeting EF, including computer-based games, aerobics, martial arts, yoga, mindfulness, and school curricula. These interventions vary in scope, as some target performance on a specific EF skill, such as cognitive flexibility, whereas others have addressed EF and self-regulation more broadly.

Interventions that have been shown to improve EF skills tend to require children to pause momentarily and reflect before responding, they generally involve repeated practice, and they get progressively more challenging as children improve. For example, in a study by Espinet, et al. (2013), children who failed the DCCS were given a new 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 red rabbit, then it goes here; but in the shape game that same red rabbit goes there.” Compared to children who received only minimal yes/no feedback (without practice in reflection) and 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. This research 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 (reduction of connections among neurons that are not used). 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.

Language can play a key role in facilitating reflection, as when one labels or describes one’s subjective experience. In a study by Jacques and Zelazo (2005), young children who were given the opportunity to label their construal of a situation were better able to consider a new, competing perspective. Children completed a modified version of the Flexible Item Selection Task (FIST; Jacques & Zelazo, 2001). In the standard version, three pictures are presented (e.g., large boat, small boat, small shoe), two of which match on shape, and two of which match on size. Children are asked to indicate two pictures that match in one way, and then are asked to indicate two pictures that match in another way. To succeed in this task, one of the stimuli, the pivot stimulus (e.g., small boat), has to be construed differently in each selection. The youngest children perform poorly on the second selection, suggesting inflexibility in their construal of the pivot stimulus. In the experimental ‘labeling’ version, some children were asked to articulate the basis for their first selection (i.e., “Why do these pictures go together?”). Children who provided such labels performed better on the second selection, suggesting that being asked to label their perspective with respect to the task stimuli required them to step out of that perspective and reflect on it, which in turn enabled children to perceive other features on which the stimuli matched.

Other interventions take a more general approach towards improving EF by focusing more broadly on self-regulation. Many of these interventions encourage reflection by providing children with self-talk strategies. An example of this type of intervention is a curriculum called Promoting Alternative Thinking Strategies (PATHS; Riggs, Greenberg, Kusché, & Pentz,. 2006). As part of the curriculum, children are taught self-control strategies through a stoplight poster that asks children to stop and consider the problem and how they feel (red), think about possible solutions to the problem (yellow), and try a solution (green) and evaluate its success. This self-talk strategy promotes reflection that in turn enables children to use EF to better regulate their classroom behavior.

2. Conclusion

Much progress has been made in measuring and describing the specific skills that constitute EF and mapping EF development across the lifespan. The IR model provides a theoretical framework through which to understand EF skills at multiple levels of analysis (cognitive, neural, emotional, subjective). Future research may usefully be directed at understanding more precisely the role that EF plays in learning, but the research reviewed highlights the importance of understanding, measuring, and cultivating reflection during childhood. Several interventions that focus on teaching reflection skills, from brief, specific exercises to classroom curricula, have demonstrated promising results. Given the importance of EF skills for facilitating early childhood learning and given their association with developmental outcomes later in life, research that improves the efficacy and delivery of these interventions is crucial.

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