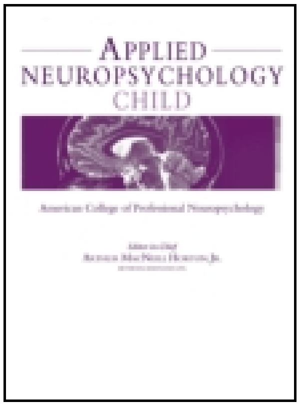

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Alfredo Ardila [a]
[a] Department of Communication Sciences and Disorders , Florida International University , Miami , Florida
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Development of Metacognitive and Emotional Executive Functions in Children

Alfredo Ardila
Department of Communication Sciences and Disorders, Florida International University, Miami, Florida

It has been proposed that two major components of executive functions can be distinguished: (1) one related to complex cognition (metacognition, such as planning, problem solving, etc.); (2) the other related to coordinating and controlling emotional behavior. Contemporary neuroimaging techniques have demonstrated that there are two distinct functional-anatomical networks within the prefrontal cortex: one associated with cognitive control and the other associated with value based decision making—each related to specific frontal-lobe areas. Metacognitive (but not emotional) executive functions have been demonstrated to be correlated with general intellectual level (intelligence). Research has shown that emotional executive functions (such as attention control) develop earlier in life (during the 1st year), before the development of metacognitive executive functions (such as planning and verbal fluency), which develop around the age of 3 and are correlated with the development of a grammatical language.

Key words: *development in children, executive functions, metacognition*

INTRODUCTION

Although it is assumed that the prefrontal cortex plays a major controlling and monitoring role, executive functions depend on extended networks involving different brain areas. Most importantly, the prefrontal cortex does not only participate in those classically recognized executive operations (sequencing, alternating, inhibiting, etc.), but also plays a core role in coordinating cognition and emotion (Mitchell & Phillips, 2007). The prefrontal lobe has extensive connections to subcortical and limbic system areas (Barbas, 2006; Damasio & Anderson, 1993; Koziol & Budding, 2009), and even its orbital portion could be regarded as an extension of the limbic system.

By coordinating cognition and emotion, the prefrontal lobe plays a major function by controlling the limbic system impulses—that is, making limbic impulses "socially acceptable" (e.g., Beer, John, Scabini, & Knight, 2006; Blair, 2004; Lezak, Howieson, Loring, & Hannay, 2004).

Consequently, two major components of executive functions could be distinguished: (1) those classically related to complex cognition (such as planning, problem solving, etc.), and (2) those related to coordinating and controlling emotional behavior. This idea has been suggested by different authors; for instance, a distinction has been proposed between the "cool" cognitive aspects of executive functions, which are more associated with dorsolateral regions of the prefrontal cortex, and the "hot" affective aspects, which are more associated with the ventral and medial regions (Zelazo & Müller, 2002). This hot/cool distinction has been applied to the development of executive functions in children (Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

TWO EXECUTIVE FUNCTION SYSTEMS

Since the first systematic report of a frontal-lobe lesion (the Phineas Gage case; Harlow, 1848, 1868), it has been noted that executive/frontal-lobe function includes two

Address correspondence to Alfredo Ardila, Department of Communication Sciences and Disorders, Florida International University, 11200 SW 8th Street, AHC3-431B, Miami, FL 33199. E-mail: ardilaa@fiu.edu

different components. As a matter of fact, most of the disturbances reported in Phineas Gage (and in many cases of prefrontal syndromes) refer to behavioral/emotional disturbances, or more exactly, disturbances in coordinating cognition and emotion/motivation. Harlow (1848, 1868) described severe emotional changes in Phineas Gage but emphasized that *no intellectual impairments were observed*; he clearly pointed out that neither his memory nor his intelligence were compromised by the brain lesion. Harlow (1848) stated that the "equilibrium or balances so to speak, between his intellectual faculties and animal propensities seem to have been destroyed. He is fitful, irreverent, indulging in gross profanity (which was not previously his custom), manifesting little or no deference for his fellows, and impatient of restraint or advice when it conflicts with his desires" (p. 389). It should be emphasized that the frontal damage in Phineas Gage involved the orbital and medial aspects, but not the prefrontal dorsolateral area (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; Ratiu & Talos, 2004; see Figure 1).

Consequently, it can be assumed that there are two different, but closely related types of executive function (e.g., Ardila, 2008; Fuster, 2002; Happaney, Zelazo, & Stuss, 2004).

Metacognitive Executive Functions

Metacognitive executive functions include problem solving, abstracting, planning, strategy development and implementation, and working memory—abilities mostly related to the dorsolateral area of the prefrontal cortex (e.g., Stuss & Knight, 2002). The dorsolateral prefrontal cortex has been observed to participate in diverse planning, abstracting, problem-solving, and working-memory tasks. Using functional magnetic resonance imaging, dorsolateral prefrontal activation has been found in tasks such as solving the Tower of Hanoi (Fincham, Carter, van Veen, Stenger, & Anderson, 2002), the Controlled Word Association Test (letter fluency; Baldo, Schwartz, Wilkins, & Dronkers, 2006), working memory (Yoon, Hoffman, & D'Esposito, 2007), and solving the Wisconsin Card-Sorting Test (Lie, Specht, Marshall, & Fink, 2006).

FIGURE 1 Trajectory of the bar in Phineas Gage's skull, according to Harlow (1848) (retrieved from https://neurophilosophy.files.wordpress.com/2006/12/phineas_gage.JPG?w=600).

Emotional/Motivational Executive Functions

Emotional/motivational executive functions are responsible for coordinating cognition and emotion, or the ability to fulfill basic impulses following socially acceptable strategies. The ventromedial areas of the prefrontal cortex are involved in the expression and control of emotional and instinctual behaviors (Fuster, 1997, 2002). This function is related with so-called "inhibitory control" of behavior (Miller & Wang, 2006). Clinical evidence (e.g., Luria, 1969; Stuss & Knight, 2002) and experimental research (e.g., Leung & Cai, 2007; Medalla, Lera, Feinberg, & Barbas, 2007) suggest that the neural substrate for this inhibitory function resides mainly in the medial and orbital portions of the prefrontal cortex.

These two types of executive functions ("metacognitive" and "emotional/ motivational") depend on relatively different prefrontal areas, and as a matter of fact, two major variants in the prefrontal syndrome are frequently distinguished, one mostly impairing cognition (or rather cognitive control—that is, "metacognition") and the other mostly impairing behavior.

Dorsolateral Syndrome. Cummings (1993) indicated that the dorsolateral circuit is the most important in executive functioning. Cortical–subcortical connections have been suggested (Koziol & Budding, 2009). The most noted deficit is an inability to organize a behavioral response to novel or complex stimuli. Symptoms are on a continuum and reflect the capacity to shift cognitive sets, engage existing strategies, and organize information to meet changing environmental demands. Various researchers, including Luria (1969), have noted perseveration, stimulus-bound behavior, echopraxia, and echolalia. Lateralization has been noted in executive dysfunction (Goldberg, 2001). The ventral and dorsal portions of the prefrontal cortex are believed to interact in the maintenance of rational and "nonrisky" decision making (Manes et al., 2002). According to Fuster (1997, 2002), the most general executive function of the lateral prefrontal cortex is the temporal organization of goal-directed actions in the domains of behavior, cognition, and language.

Orbitofrontal and Medial Frontal Syndrome. Orbitofrontal damage has been associated with disinhibition, inappropriate behaviors, personality changes, irritability, mood liability, tactlessness, distractibility, and disregard of important events (Stuss & Knight, 2002). These patients are unable to respond to social cues. Of note, it was observed by Laiacona and colleagues (1989) that these patients have no difficulty with card-sorting tasks. Eslinger and Damasio (1985) coined the term "acquired sociopathy" to describe deregulation that couples both lack of insight and remorse regarding these behaviors. The orbitofrontal cortex appears to be linked predominantly to limbic and basal forebrain sites. Medial frontal-lobe damage causes apathy or abulia (a severe form of apathy). Acute bilateral lesions in the medial-frontal area can cause akinetic mutism, in which the individual is awake and has self-awareness but does not initiate behaviors (Ross & Stewart, 1981). According to Fuster (1997, 2002), the ventromedial areas of the prefrontal cortex are involved in expression and control of emotional and instinctual behaviors.

It is evident that the two prefrontal syndromes can have rather different clinical expressions (metacognitive and emotional/motivational) depending upon the specific location of the damage. For Phineas Gage, the disturbance was observed in controlling emotions and instinctual behaviors; it was associated with damage at the orbitofrontal and medial-frontal areas. The dorsolateral prefrontal cortex was not damaged, and cognition was unimpaired.

There is robust evidence to assume that two different prefrontal systems support these two executive function subtypes. For instance, Gläscher et al. (2012) used voxel-based lesion symptom mapping (i.e., method and software for analyzing relationships between behavioral deficits in neurological populations and lesion sites associated with those deficits) in 344 individuals with focal brain lesions, including 165 involving prefrontal pathology; a comprehensive neuropsychological test battery was administered to all participants. It was demonstrated that there are two distinct functional-anatomical networks within the prefrontal cortex: (1) one associated with cognitive control (that is, "metacognitive executive functions," including response inhibition, conflict monitoring, and switching), and supported by the dorsolateral prefrontal cortex and anterior cingulate cortex; and (2) a second functional-anatomical network associated with value-based decision making ("emotional/motivational executive functions"), which included the orbitofrontal, ventromedial, and frontopolar cortex.

EXECUTIVE FUNCTIONS IN CHILDREN

Executive functions rapidly develop through childhood; this development is clearly correlated with the maturation of the frontal lobes (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001). Different growth periods have been proposed: the period from birth to 2 years of age; from 7 to 9 years of age; and a finally, from 16 to 19 years of age. This means that the brain maturation and the associated cognitive abilities do not grow in a steady and continuous way, but there are certain periods when progress is more notorious.

Regardless of the difficulties in measuring executive functions in children (Hughes & Graham, 2002), several studies have analyzed the early development of executive functions. Some executive functions that have been analyzed through ontogeny are: attentional control, planning, set shifting, and verbal fluency (see Jurado & Rosselli, 2007, for a review). Jurado and Rosselli emphasize that the first executive function to emerge, by the child's 1st year, is the ability to inhibit overlearned behavior, resulting in increased attentional control; however, its greatest development is some time later (around 6 to 10 years of age). Other executive abilities, for instance planning and set shifting, develop later, around age 3 with significant improvement after age 7. Verbal fluency (a language-mediated executive function) is the last to emerge and is significantly influenced by environmental factors. All executive functions, nonetheless, continue to improve until adolescence.

Hongwanishkul et al. (2005) assessed different executive functions in 3- to 5-year-old children using two putative measures of cool (metacognitive) executive functions (Self-Ordered Pointing and Dimensional Change Card Sort) and two putative measures of hot (emotional) executive functions (Children's Gambling Task and Delay of Gratification). Findings confirmed that performance on both types of tasks develops during the preschool period. However, the measures of hot (emotional) and cool (metacognitive) executive functions showed different patterns of relations to each other and to measures of general intellectual function and temperament: Whereas cool (metacognitive) executive functions significantly correlated with general intellectual ability ("intelligence"), hot (emotional) executive functions were not related to general intellectual functioning (verbal mental age and performance mental age).

Matute et al. (2008) analyzed the influence of age on the performance of a planning and organization task (two skills included in the metacognitive executive functions), using the so-called "Mexican pyramid" (a test similar in principle to the Tower of London Test; Shallice, 1982). Its purpose was to measure problem-solving ability, and it was taken from the *Evaluación Neuropsicológica Infantil* (Child Neuropsychological Assessment [ENI]; Matute, Rosselli, Ardila, & Ostrosky-Solís, 2007); 239 school-age children from México and Colombia, distributed into six age groups, were selected. Five measures were analyzed: number of correct designs, number of movements per design, execution time in the correct designs, number of correct designs built with the minimum of movements, and its execution time. A significant effect of age on the five measures was found. Comparison

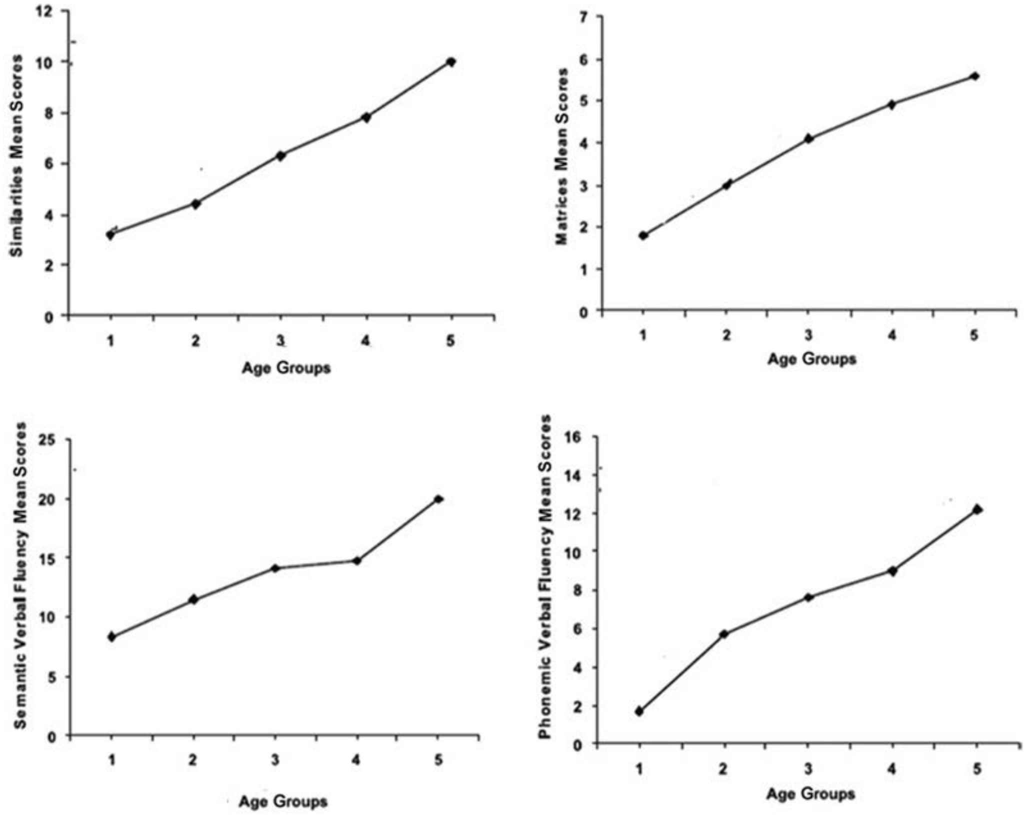

FIGURE 2 Scores in four selected executive tests (1 = 5 to 6 years; 2 = 7 to 8 years; 3 = 9 to 10 years; 4 = 11 to 12 years; 5 = 13 to 14 years; adapted from Ardila et al., 2005).

between groups showed that younger children (5 to 6 years old) had a smaller number of correct designs, while children aged 5 to 8 years old needed more movements. Execution time showed a greater number of differences between groups. According to the authors, the results supported the notion that the development of planning and organization is fast in the 1st years of school age and slows down in adolescence.

Ardila, Rosselli, Matute, and Guajardo (2005) reported the developmental pattern of different executive functions between the ages of 5 to 6 years old and 13 to 14 years old, using 315 participants taken from public schools (156 boys and 159 girls) and divided into five age ranges (5 to 6 years old, 7 to 8 years old, 9 to 10 years old, 11 to 12 years old, and 13 to 14 years old). The scores in several executive function subtests taken for the ENI (Matute et al., 2007) were analyzed. The results in four selected metacognitive executive functions are presented here: (1) For Semantic Verbal Fluency, children were instructed to name all animals they could in 1 minute. The score was the total number of animals named correctly. (2) For Phonemic Verbal Fluency, children were instructed to say as many words starting with M as they could in 1 minute. The score was the total number of correct words. (3) For Similarities, children were requested to find commonalities between pairs of words (concept formation). Eight pairs of words were presented, one at a time. Abstract generalizations or categorizations (i.e., “A dog and a cat are animals”) were scored with 2 points; specific and descriptive answers (i.e., “A dog and the cat have four legs”) were scored with 1 point, and incorrect answers received a 0. The maximum score was 16. (4) Matrices was a multiple-choice subtest consisting of a series of visual pattern- matching and analogy problems pictured in nonrepresentational designs. It required the child to conceptualize spatial and design relations such as in Raven’s Progressive Matrices (Raven, Court, & Raven, 1976). One point is given to each option correctly selected by the child. The maximum score is 8. Figure 2 presents the development of the scores in these four selected executive function tests.

Improvement between the first (5 to 6 years old) and the last age range (13 to 14 years old) was observed in the four tests, but it was highest for the Phonemic Verbal Fluency Test (the score among the oldest children was about 7 times greater than among the younger children), whereas in the other three tests, the score in the oldest group was only about 3 times greater than in the younger group.

CONCLUSIONS

Some tentative conclusions can be drawn:

1. There is converging evidence that so-called "executive functions" include two different components supported by two different brain systems ("emotional/motivational" and "metacognitive," sometimes referred as "hot" and "cool").
2. Contemporary neuroimaging techniques have demonstrated that there are two distinct functional-anatomical networks within the prefrontal cortex: one associated with cognitive control (the dorsolateral prefrontal cortex and anterior cingulate cortex), and the other associated with value-based decision making (the orbitofrontal, ventromedial, and frontopolar cortex.)
3. Metacognitive executive functions (but not emotional executive functions) are correlated with the child's general intellectual level (intelligence).
4. Contemporary research has shown that emotional executive functions (such as attentional control) developed earlier in life (during the 1st year), before the development of metacognitive executive functions (such as planning and verbal fluency), which develop around the age of 3, correlate with the development of grammatical language (Ardila, 2009). A similar sequence has been suggested for the historical evolution of executive functions (see Ardila, 2008, for a review). In this regard, ontogeny recapitulates phylogeny.

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