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Executive function in children born preterm: Risk factors and implications for outcome

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Abstract

Executive function (EF) refers to the set of cognitive processes involved in the self-regulation of emotion and goal-directed behavior. These skills and the brain systems that support them develop throughout childhood and are frequently compromised in preterm children, even in those with broadly average global cognitive ability. Risks for deficits in EF in preterm children, and attendant problems in learning and psychosocial functioning, are higher in those with more extreme prematurity, neonatal complications, and related brain abnormalities. Associations of higher levels of EF with more supportive home and school environments suggest a potential for attenuating these risks, especially with early identification. Further research is needed to understand how deficits in EF evolve in preterm children, refine assessment methods, and develop interventions that either promote the development of EF in this population or help children to compensate for these weaknesses.

Keywords

executive function; preterm birth; child development

Executive function in children

Defining characteristics

In everyday life, we are continually challenged to self-regulate our emotional and behavioral responses. Demands for self-regulation change over the course of the lifespan. In infancy, self-regulation centers on basic homeostatic processes, such as managing cycles of arousal,[1] but with extrinsic input from the caregiver. Increasingly through the course of childhood, children are expected to manage their emotions and behavior intrinsically and of their own volition. To engage effectively in autonomous, proactive self-regulation, the child requires

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an ability to mentally represent the goal he/she is trying to achieve, to filter out conflicting, irrelevant responses or sensory stimuli that detract from this goal-directed focus, to plan for different contingencies, and to flexibly adjust his/her goals relative to changing cues or signals in the environment. The set of higher-order mental capacities that support this independent, goal-directed behavior is referred to collectively as 'executive function'.[2,3] An alternative term sometimes used to emphasize the top-down nature of this support is executive or cognitive 'control'.[4] Use of the broader term 'self-regulation' is also justified by associations of EF with the ability to modulate emotions.[4–7]

Higher levels of cognitive and emotional self-regulation in children and youth are associated with more positive temperaments, more advanced language and academic skills, better behavioral and social adjustment and social problem solving, and more successful coping with environmental stressors.[7–13] Conversely, longitudinal research has linked difficulties in self-regulation in early childhood with subsequent weaknesses in academic achievement and more negative long-term health, educational, and behavioral outcomes. Studies of community samples indicate that weaknesses in EF in preschool predict lower levels of mathematics and reading readiness skills at early school age.[14–16] In the Dunedin (New Zealand) longitudinal study, weaker self-control skills at ages 3–5 years were related to poorer health, lower wealth, and more polysubstance dependence in adulthood.[17] Another study found that greater difficulties on a delayed gratification task in early childhood predicted lower self-esteem and coping abilities, more substance abuse, and lower educational levels in adults with a personality style characterized by sensitivity to rejection.[18]

Component processes

Cognitive scientists have differing definitions of EF and the various mental processes that fall under its rubric.[19,20] Past debates have centered around the nature of the components of EF and on whether to conceptualize EF as a set of distinct component skills or as manifestations of a unified core function. A compromise position integrated these perspectives by acknowledging a set of component EFs that are partially independent but linked together by a common underlying process, such as executive control, goal-maintenance, inhibition, or conflict resolution.[6,19,21] Typically, at least three cognitive processes are referenced in broader definitions of EF: working memory - the ability to mentally represent and manipulate information over short time intervals; inhibitory control–the ability to suppress attention or responses to an irrelevant stimulus; and cognitive flexibility–the ability to switch fluidly between different goals, tasks or stimuli.[3,21] Given this multi-component conceptualization of EF, tasks used to assess it can have diverse demands. A common task to assess working memory, for example, involves counting an array of dots over a series of trials and then repeating back the sequence of count values from all previous trials.[22] Inhibitory control often is assessed using tasks that involve suppressing a prepotent response to a stimulus (e.g. say 'day' when one sees a picture of a moon or read the word 'red' when the word 'red' is printed in green ink). Other examples of tasks that are used to assess EF are listed in Table 1, along with examples of similar tasks that have been simplified for use with young children. Although they vary in format and response demands, all of these tasks require the child to maintain a conscious goal or rule in mind and to use this rule to guide his/her responses while resisting competing impulses or distractors.

More complex executive tasks, such as those requiring planning, organization, problem-solving, and fluid reasoning, and appreciation of false beliefs or others' perspectives (i.e., theory of mind) can then be construed as involving combinations of these processes and higher-level mental representations.[3,29] For example, solving a puzzle-type task such as Tower of Hanoi, which involves moving disks on pegs to reproduce a target arrangement of the disks, requires keeping rules for moving the disks in mind (working memory) while inhibiting actions that would break the rules. Similarly, tests of phonemic fluency, which require timed generation of words beginning with specified letters, entail inhibition of words beginning with other letters, working memory for words already produced, and flexibility in shifting from one search strategy to another. A further distinction is sometimes made between 'cool' versus 'hot' EF. Cool EF is assessed using measures that are more purely cognitive in nature, such as tasks of working memory or attention switching. In contrast, hot EF is involved in decisions that are emotionally-laden or have motivational significance, as exemplified by responses to delayed gratification or gambling tasks. Research suggests that these two types of EF are weakly related, have different associations with other traits such as IQ and temperament, and develop independently on one another.[30,31]

Developmental changes

EF develops as infants begin to selectively attend to aspects of their environment. This process occurs with maturation of the anterior, or 'voluntary,' attention system and with the concomitant abilities to exert control over the more automatic 'orienting' attention system, form and retain mental representations of objects, activities, and goals, sustain attention over time, and shift attention in accordance with task demands.[19,32] Children's performance on measures of working memory, inhibitory control, and cognitive flexibility increases dramatically between 2 and 5 years of age, although slower gains in the ability to complete increasingly abstract and complex executive function tasks are evident through middle childhood and adolescence.[3,33,34] Cognitive flexibility requires coordination working memory and inhibition and thus matures subsequent to more elementary forms of the latter EF components.[19,35–37] There is also evidence for changes in the nature of EF over the course of childhood. In preschool-aged samples, findings from confirmatory factor analyses suggest that tests of different types of EF tap a single skill rather than distinct component functions.[11,20,38] Factor analytic research in community cohorts of school-age children and adolescents provides support for greater differentiation of EF into the component processes of working memory, inhibitory control, and cognitive flexibility in these older age groups.[6,39,40]

Neural systems

Findings from neural activation studies using functional magnetic resonance imaging (fMRI) during EF tasks indicate that several distributed frontal-subcortical systems contribute to EF, each of which is linked to other brain regions. The dorsolateral prefrontal, posterior parietal, and temporal cortices, supplementary motor area, anterior cingulate, basal ganglia, and cerebellum have been implicated in the cognitive control aspects of EF; the dorsolateral, ventrolateral, and dorsomedial prefrontal cortices, along with the pregenual cingulate and amygdala in emotion regulation; and the orbitofrontal cortex, ventrolateral prefrontal cortex, dorsal anterior cingulate cortex, and ventral striatum in reward processing.[4,32,41–45] Brain insults to these systems have the potential to disrupt cognitive control or emotion regulation or to interfere with goal directed behavior.

Developmental studies suggest that the neural systems that support EF evolve throughout childhood and adolescence. For instance, fMRI studies comparing children and adults on the same EF tasks reveal age-related changes in patterns of brain activation. In a study of visual-spatial working memory, children and adolescents had activation in the striatum and cerebellum whereas patterns of activation in adults were confined to prefrontal and parietal regions.[46] Other studies have found trends for more specific and focused activations with increasing age on tasks of inhibition and working memory.[47–49] In resting state fMRI, which involves scanning youth who are resting passively without engagement in a cognitive task, temporal fluctuations in activation across neural regions included in the executive control network become increasingly synchronized and anti-correlated with other neural networks over the course of adolescence, suggesting that these networks are becoming increasingly refined and specialized for the coordination of goal-directed behavior.[50–52] At a structural level, executive task performance increases in step with the development of long-range white matter connectivity, as measured by diffusion weighted imaging,[53,54] as well as with reductions in inferior frontal and anterior cingulate cortical thickness, which presumably occur as a result of synaptic pruning and myelination.[55] Consequently, the effects of insults to brain regions contributing to EF are likely to be age-dependent.

Effects of preterm birth on executive function

Brain abnormalities in preterm children and related deficits in executive function

Children with more pronounced degrees of preterm birth [gestational age (GA) <37 weeks] or low birth weight (<2500 g) are at risk for reduced brain volumes in the structures associated with EF, including cerebral white matter, frontal, parietal, and temporal cortices, and the basal ganglia and cerebellum.[56–61] Not surprisingly, these children have a wide range of deficits in EF compared to term-born normal birth weight (NBW) controls, with deficits proportional to the degree of prematurity.[62–65] Impairments in EF are especially prominent in extremely preterm birth/extremely low birth weight (GA <28 weeks and/or <1000 g) and very preterm/very low birth weight (GA <32 weeks and/or <1500 g) samples,[66–68] but are evident even in moderate (GA 32–33 weeks) and late (34–36 weeks) preterm children.[69–71] Although children and youth with varying degrees of preterm birth/low birth weight are referred to in this paper as ‘preterm’ children, impairments vary with the degree of prematurity.[64]

EF deficits are evident across a wide range of tests, on parent and teacher ratings of behavioral symptoms of EF deficits and of poor emotion self-regulation, and on direct observations of emotional self-regulation in early childhood.[66,72–75] Two meta-analyses found that the performance of children born preterm on measures of executive control is, on average, 0.3 to 0.6 standard deviations lower than that of full term children,[63,64] although effects as great as 1 standard deviation have been reported in studies of children with extreme prematurity.[76] Rates of deficits in EF relative to age standards on tests and parent and teacher ratings are substantially higher for children with more extreme prematurity compared to NBW controls, with rates 2 to 4 times higher in one sample[65] and 3 to 5 times higher in another.[67] Impairments in EF are found even when excluding children with low IQs or when adjusting group comparisons for IQ or estimates of 'crystallized' intelligence based on vocabulary knowledge.[62,65,74,77–82] More complex and cognitively demanding tests, such as those requiring a greater load on working memory or more steps to solve a puzzle-type task, have greater sensitivity to subtle impairments, such as those exhibited by children with less extreme prematurity.[69,83–85]

Development of executive function in preterm children

As early as toddlerhood, children born preterm show impairments on spatial working memory tasks as well as difficulties regulating their emotions.[73,82,86–88] As preschoolers, they show difficulties on 'cool' measures of inhibitory control, as well as on 'hot' measures that require waiting for a reward.[69,70,83,89,90] By school age, preterm-born children not only show greater impairments on measures of working memory, switching, and verbal fluency but also are less likely to show evidence of strategic planning during complex problem solving tasks.[9,62,65,74,91,92] Parents also report impairments in everyday aspects of executive function, such as remembering homework books or planning activities ahead of time.[74,93] Studies tracking preterm samples into young adulthood have reported difficulties in selective attention, inhibitory control, cognitive flexibility and working memory.[81,94,95] In addition, functional neuroimaging studies suggest that adults born preterm may recruit different neural networks than full term controls when performing executive tasks, including showing less suppression of posterior 'default mode' network regions that typically are deactivated during cognitive tasks.[96–98] Taken together, these studies suggest that EF difficulties are evident even before preterm children enter the classroom and that they persist throughout the lifespan.

There is some evidence from cross-sectional studies for diminishing weaknesses with age in sustained and selective attention and in response inhibition, and for increasing difficulties with age in verbal fluency.[62–64] However, researchers acknowledge difficulties in drawing firm conclusions regarding age trends given that deficits in the preterm children were more evident in samples comprised of more extremely preterm children and that findings were dependent on the measures used to assess EF. Few studies have conducted repeated assessments of preterm children over time using the same measures, but those that have also support the possibility of age-related changes in emotion regulation and executive control in preterm samples.[73,99,100] Clark et al.[73] followed groups of extremely preterm children, very preterm children, and NBW controls from 2–4 years of age. Emotion regulation was assessed on parent ratings of the children and via observation of parent-child interactions during problem solving activities. Findings indicated that both of the preterm groups were behind the NBW group on a composite measure of emotion regulation at 2 years of age, whereas only the extremely preterm group remained behind the controls on this measure at 4 years. Those extremely preterm children with continued delays were more likely to have shown abnormalities on cerebral MRI scans at birth, consistent with the idea that neonatal brain insults associated with preterm birth may impinge on the slowly developing neural network that supports EF. In a longitudinal study of children with <750 g birth weight compared to those with 750–1499 g birth weight and NBW controls, Taylor et al.[68] found that the <750 g group had stable deficits from ages 7–14 years on most cognitive measures but made slower progress than the NBW group on measures of EF. The increasing gap over time between the groups on a measure of working memory and set switching is depicted in Figure 1.

Risks for deficits in executive function

Both biological and environmental factors help to account for variability in EF outcomes in preterm children. White matter abnormalities on structural and diffusion-weighted MRI are the most consistent and robust correlates of deficits in EF in preterm children.[61,88–90,101–103] Volumetric measures of subcortical structures, including the caudate, thalamus and hippocampus, also correlate with EF in this population and a recent Norwegian study showed that lower medial frontal and temporal surface area correlated with poorer EF in adolescents born preterm.[59,104,105] Other biological factors related to EF in these children, in addition to lower GA and birth weight, include being small for GA (SGA), brain abnormalities on clinical interpretations of neonatal cranial ultrasounds or conventional MRI (i.e., indications of periventricular leukomalacia, intraventricular hemorrhage, or ventricular enlargement), bronchopulmonary dysplasia, postnatal steroids, retinopathy of prematurity, sepsis, and male gender.[65,67,74,78–80,101,106–108] Children who display neurosensory impairments (cerebral palsy or vision or hearing disorders) or delayed early development are also at increased risk for impairments in EF.[67] However, neural abnormalities are not always associated with deficient EF. Nosarti et al.[109] found that very preterm adolescents showed different patterns of brain activation during a fMRI task requiring response inhibition compared to age-matched NBW controls. Because both groups performed well on the task, the results were interpreted as suggesting neural compensation for areas of the brain compromised by preterm birth.

Environmental factors related to poorer EF include lower socioeconomic status, less child-focused home environments, and suboptimal parenting styles.[29,38,72–74,110] Families of preterm children are more likely to experience higher levels of stress and to have fewer socio-economic resources.[111,112] Given that children born preterm already have neural and physiological vulnerabilities, they may be even more vulnerable to the deleterious effects of these stressors.[113] Unfortunately, few studies have focused on the joint roles of medical and social risk in shaping executive function outcomes in children born preterm, an important oversight given the potential role of family-based interventions in fostering EF in this population. In one study, young low birth weight children whose parents who were more warm and responsive to the child during structured play activities caught up to NBW controls on measures of EF between ages 3 and 5 years, whereas parents of low birth weight children who were more harsh and intrusive during these interactions remained behind.[114]

Relation of deficits in executive function to behavior and academic achievement

Deficits in EF are of special interest in assessing outcomes of preterm birth, not only because of their relation to brain abnormalities in this population but also because of their value in predicting behavior and academic achievement. These deficits are associated with interview-based diagnoses of attention deficit hyperactivity disorder (ADHD), parent and teacher ratings of ADHD and dysexecutive behaviors, weaknesses in academic achievement and social problem-solving skills, and inadequate readiness for learning at school entry.[4,14,91,115–119] Clark and Woodward[72] found that EF at school entry fully accounted for the relation of preterm birth to lower academic achievement at age 9 years. Similarly, Rose et al.[120] reported that working memory scores accounted for the variability in reading and mathematics achievement among children born preterm. Using a novel approach that incorporated observational measures of kindergarten classroom behavior, Wong et al.[121] found increased rates of competing, off-task behaviors and a greater reliance on teacher support and intervention in an extremely preterm sample. These negative academic behaviors were more common among children who scored less well on tests of working memory and inhibitory control administered in a research lab. Scott et al.[118] reported that tests of EF but not of IQ predicted propensities to behavior problems in this same sample. Specifically, poor performance on measures of working memory, inhibitory control and switching predicted a 4- to 9-fold increase in the likelihood meeting criteria for ADHD-combined type, a 3- to 5-fold increase in meeting criteria for ADHD-inattentive type and a 4- to 11-fold increase in the odds of having difficulties in emotional control in this group of children. Executive impairments thus impede early learning in children born preterm and measures of EF may be more prognostic of behavioral adjustment difficulties than other cognitive tests.

Assessment and intervention of executive function in preterm children

Assessment issues

Despite high rates of impairments in EF in children with preterm birth, especially in those with more extreme degrees of prematurity, we are unaware of any programs that routinely assess EF in this population. Associations of deficits in EF with classroom behavior, academic readiness, and achievement skills suggest that screening for these problems may be useful prior to school entry and whenever learning or behavior problems become evident in these children. Follow-up studies from the preschool to school-age years indicate that deficits in EF in higher functioning children may not be evident in early childhood and that these problems are frequently overlooked.[122,123] Teachers may also fail to understand the cognitive implications of preterm birth and thus may either fail to identify these problems or lack an understanding of the specific nature of the child’s difficulties and instructional needs.[124] Because of variability in the sensitivity and reliability of individual EF tests, as well as studies indicating that tests contribute to broader ability constructs,[7,38] use of test composites may be useful in assessing EF in both research and clinical applications.[13,61,90] Despite disparities in outcomes between behavior ratings of deficits in EF and tests of EF, findings from a recent study suggest that these two types of measures account for unique variance in adaptive functioning in preterm children.[125] These results may be related to the fact that tests provide more precise assessments of cognitive control, whereas behavior ratings assess these skills under less structured conditions and thus may better evaluate the child’s ability to meet everyday demands for self-regulation of behavior and emotions. Consequently, a multi-method assessment approach will be essential to better understand the breadth of a child’s EF impairments.

Intervention

Interventions to alleviate the weaknesses in EF in children born preterm may begin as early as in the neonatal intensive care unit (NICU). In a randomized trial of Kangaroo care, preterm neonates who received the intervention in the NICU showed enhanced physiological regulation, including increased vagal tone, a marker of autonomic regulation, and enhanced sleep-wake rhythmicity.[126] They also showed enhanced EF performance relative to the control group at age 10 years. This study suggests that procedures that facilitate physiological regulation and parent-child attachment in the NICU may have long-term benefits for children's executive control.

Associations of EF with socioeconomic status, parent mental health, and parenting style imply a potential for training programs or instructional interventions to enhance these skills in preterm children.[127,128] Approaches to early elementary instruction and classroom ecology that place emphasis on building self-regulation and planning skills have also produced gains in EF and achievement.[4,129–131] Computerized cognitive training targeting working memory and inhibitory control is another potentially fruitful form of EF intervention, with evidence for intervention-related improvements in untrained cognitive measures of similar and related skills, as well as for changes in underlying neural processes.[129,132] In a Norwegian study, preterm children completed 'Cogmed', a computer game-like training course lasting approximately 5 weeks.[133] Children who completed the intervention showed moderate improvements on measures of attention and EF, with similar improvements reported in an adolescent sample,[134] though doubts have been raised with regard to the degree to which these benefits generalize to improved learning or social-emotional functioning.[135,136]

Summary and conclusions

Problems in EF, broadly construed as the capacity to self-regulate cognition and behavior in goal-directed activities, are common sequelae of preterm birth. These problems are evident in children with generalized cognitive limitations but can also occur as relatively selective deficits in inhibition, working memory, or cognitive flexibility. Behavioral manifestations of these deficits include poor organizational and self-monitoring skills and difficulties in emotion self-regulation. These deficits are also associated with behavior and learning problems, including increased risk for ADHD, weaknesses in social cognition, and poor academic achievement, particularly in the area of mathematics[14,15]. Risks for deficits in EF are heightened in children with more extreme prematurity, neonatal complications, and neural abnormalities. The development of EF is additionally related to environmental characteristics such as socioeconomic status, parenting styles, and learning experiences. Interventions, therefore, have the potential to reduce the adverse effects of preterm birth on EF and attenuate associated problems in learning and behavior.

Because deficits in EF are evident in early childhood and persist into adulthood, longitudinal follow-up of children from birth may help to identify both the earliest harbingers of EF deficits and their principal manifestations at various points along the age continuum. Recognizing early signs of impaired EF may also provide insight into strategies for limiting age-related worsening or emergence of these deficits.[11,37,63] Particularly interesting are the positive longitudinal associations between neonatal physiological regulation - including more variable vagal tone and more stable sleep-wake cycles–and later EF in this population.[137] Such findings suggest that there may be ‘heterotypic continuity’ in patterns of self-regulation across childhood, with dysregulation manifesting in different ways across the lifespan. Developmentally-nuanced studies are needed to determine if physiological and behavioral markers of regulation in infancy can identify the children most prone to executive control difficulties later in life.

Studies linking EF deficits to longer-term outcomes also highlight the importance of understanding how EF may interact with factors such as home or school quality to increase or decrease a child’s risk for subsequent learning and behavior problems. Some theorists have suggested that strong EF may operate as a protective factor in children at risk, helping them to adapt to perturbations in other cognitive domains.[138] Given that the executive system may already be compromised by preterm birth, it is possible that the preterm brain may be less resilient in the face of other developmental challenges. One natural challenge is that of cognitive aging. To our knowledge, only one study has examined executive function in older adults born preterm, finding that those preterm adults with less education were more vulnerable to executive impairments and indications of Alzheimer’s risk than those with higher education or those born full term.[139]

Enhanced measurement of EF is another important research goal. Tests of EF place demands on both EF and other cognitive skills, such as processing speed, memory, and visual spatial or motor abilities.[36,41,64] Confounds of measures of EF with non-EF processes are less of a concern in research studies that take advantage of confirmatory factor analyses that help identify latent EF constructs, but are problematic in interpreting results from tests administered in clinical evaluations. Similarly, because tests of EF typically tap multiple component EF skills, it is difficult to determine the deficits contributing most to a low test score.[41] Developing methods to identify specific EF weaknesses will be useful in establishing the neural basis of these deficits and in formulating intervention approaches. Models of how this might be accomplished are provided by experimental approaches that manipulate test demands to assess distinct component functions.[10,86,116] Because the sensitivity of tests of EF to the effects of preterm birth differs for children of varying ages and degrees of prematurity, different types of tests at varying levels of complexity will be needed to optimize assessments of individual children.[20,36] Such initiatives will be especially critical in improving assessments of EF in toddlers and preschool-age children; few existing measures designed for this age range are well standardized and have validated clinical cut-offs for impairment. A related goal is to better understand the contributions of laboratory-based assessments of EF to functional outcomes, such as learning, behavior, socialization, and quality of life. The development of measures of EF that are more contextually similar to the application of EF skills in activities of daily living, such as planning a trip to the zoo or baking a cake, may provide assessments that relate more closely to functional outcomes.[41,140]

Finally, further research will be useful to determine the utility of existing interventions, such as cognitive training and changes in classroom ecology, in improving EF in preterm children, or if modifications of these methods might optimize their benefits for these children. Alternatively, other approaches could be developed to 'work around' or compensate for children's weaknesses in EF, perhaps through individualized approaches to instruction that are more structured or less dependent on EF. It will also be essential to take other cognitive weaknesses in preterm children into account in designing interventions, such as impairments in memory, visual spatial skills, and perceptual-motor abilities.[79,119,141] Efforts to reduce the rates of learning and behavior problems in this population will require appreciation of all cognitive and socio-emotional vulnerabilities.

References

1. Weisman O, Magori-Cohen R, Louzoun Y, Eidelman AI, Feldman R. Sleep-wake transitions in premature neonates predict early development. Pediatrics. 2011; 128:706–714. [PubMed: 21911350]
2. Denckla, M. A theory and model of executive function: a neuropsychological perspective. In: Lyon, GR.; Krasnegor, NA., editors. Attention, memory, and executive function. Baltimore: Paul H. Brooks; 1996. p. 263-278.
3. Diamond A. Executive functions. Annu Rev Psychol. 2013; 64:135–168. [PubMed: 23020641]
4. Blair C, Diamond A. Biological processes in prevention and intervention: the promotion of self-regulation as a means of preventing school failure. Dev Psychopathol. 2008; 20:899–911. [PubMed: 18606037]
5. Carlson SM, Wang TS. Inhibitory control and emotion regulation in preschool children. Cog Dev. 2007; 22:489–510.
6. Cassidy AR. Executive function and psychosocial adjustment in health children and adolescents: a latent variable modelling investigation. Child Neuropsychol. 2016; 22(3–4):292–318. [PubMed: 25569593]
7. Espy KA, Sheffield TD, Wiebe SA, Clark CAC, Moehr MJ. Executive control and dimensions of problem behaviors in preschool children. J Child Psychol Psychiatry. 2011; 52(1):33–46. [PubMed: 20500238]
8. Buckner JC, Mezzacappa E, Beardslee WR. Self-regulation and its relations to adaptive functioning in low income youths. Am J Orthopsychiatry. 2009; 79(1):19–30. [PubMed: 19290722]
9. Burnett AC, Scratch SE, Anderson PJ. Executive function outcome in preterm adolescents. Early Hum Dev. 2013; 89:215–220. [PubMed: 23455604]
10. Chevalier N, Sheffield TD, Nelson JM, Clark CAC, Wiebe SA, Espy KA. Underpinnings of the costs of flexibility in preschool children: the roles of inhibition and working memory. Dev Neuropsychol. 37(2):99–118.
11. Hughes C, Ensor R, Wilson A, Graham A. Tracking executive function across the transition to school: a latent variable approach. Dev Neuropsychol. 2010; 35(1):20–36. [PubMed: 20390590]
12. Nigg JT, Quamma JP, Greenberg MT, Kusche CA. A two-year longitudinal study of neuropsychological and cognitive performance in relation to behavioral problems and competencies in elementary school children. J Abnorm Child Psychol. 1999; 27(1):51–63. [PubMed: 10197406]
13. Willoughby M, Blair C. Test-retest reliability of a new executive function battery for use in early childhood. Child Neuropsych. 2011; 17(6):564–579.
14. Blair C, Razza RP. Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. Child Dev. 2007; 78(2):647–663. [PubMed: 17381795]
15. Clark CAC, Pritchard VE, Woodward LJ. Preschool executive functioning abilities predict early mathematics achievement. Dev Psychol. 2010; 46(5):1176–1191. [PubMed: 20822231]
16. Viterbori P, Usai MC, Traverso L, De Franchis V. How preschool executive functioning predictors several aspects of math achievement in grades 1 and 3: a longitudinal study. J Exp Child Psychol. 2015; 140:38–55. [PubMed: 26218333]

17. Moffitt TE, Arseneault L, Belsky D, et al. A gradient of childhood self-control predicts health, wealth, and public safety. Proc Natl Acad Sci. 2011; 108(7):2693–2698. [PubMed: 21262822]
18. Ayduk O, Mendoza-Denton R, Mischel W, Downey G. Regulating the interpersonal self: strategic self-regulation for coping with rejection sensitivity. J Pers Soc Psychol. 2000; 79(5):776–792. [PubMed: 11079241]
19. Garon N, Bryon SE, Smith IM. Executive function in preschoolers: a review using an integrative framework. Psychol Bull. 2008; 134(1):31–60. [PubMed: 18193994]
20. Wiebe SA, Espy KA, Charak D. Using confirmatory factor analysis to understand executive control in preschool children: I. Latent Structure. Dev Psychol. 2008; 44:575–587. [PubMed: 18331145]
21. Miyake A, Friedman N, Emerson M, et al. The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. Cog Psychol. 2000; 41:49–100.
22. Case R, Kurland DM, Goldberg J. Operational efficiency and the growth of short-term memory span. J Exp Child Psychol. 1982; 33:386–404.
23. Daneman M, Carpenter P. Individual differences in working memory and reading. J Verbal Learning Verbal Behav. 1980; 19:450–466.
24. Diamond A. The development and neural bases of memory functions as indexed by the AB and delayed response tasks in human infants and infant monkeys. Ann N Y Acad Sci. 1990; 608:267–309. [PubMed: 2127511]
25. Kongs, S.; Thompson, L.; Iverson, G.; Heaton, R. Wisconsin Card Sorting Test-64 Card Version. Manual. Odessa, FL:
26. Zelazo PD. The Dimensional Change Card Sort (DCCS): a method of assessing executive function in children. Nat Protoc. 2006; 1:297–301. [PubMed: 17406248]
27. Logan GD, Cowan WB, Davis KA. On the ability to inhibit simple and choice reaction time responses: a model and a method. J Exp Psychol Hum Percept Perform. 1984; 10:276–291. [PubMed: 6232345]
28. Wiebe SA, Sheffield TD, Espy KA. Separating the fish from the sharks: a longitudinal study of preschool response inhibition. Child Dev. 2012; 83(4):1245–1261. [PubMed: 22533453]
29. Friedman SL, Scholnick EK, Bender RH, et al. Planning in middle childhood: early predictors and later outcomes. Child Dev. 2014; 85(4):1446–1460. [PubMed: 24476334]
30. Hongwanishkul D, Happaney KR, Lee WSC, Zelazo PD. Assessment of hot and cool executive function in young children: Age-related changes and individual differences. Dev Neuropsychol. 28(2):617–644.
31. Zelazo PD, Carlson SM. Hot and cool executive function in childhood and adolescence: development and plasticity. Child Dev Perspectives. 2012; 6(4):354–360.
32. Rothbart, M.; Posner, M. Mechanism and variation in the development of attentional networks. In: Nelson, C.; Luciana, M., editors. Handbook of Developmental Cognitive Neuroscience. Cambridge, MA: MIT press; 2001. p. 353-363.
33. Anderson VA, Anderson P, Northam E, Jacobs R, Catroppa C. Development of executive functions through late childhood and adolescence in an Australian sample. Dev Neuropsychol. 2001; 20(1): 385–406. [PubMed: 11827095]
34. Best JR, Miller PH. A developmental perspective on executive function. Child Dev. 2010; 81(6): 1641–1660. [PubMed: 21077853]
35. Best JR, Miller PH, Jones LL. Executive functions after age 5: changes and correlates. Dev Rev. 2009; 29:180–200. [PubMed: 20161467]
36. Carlson S. Developmentally sensitive measures of executive function in preschool children. Dev Neuropsychol. 2005; 28:595–616. [PubMed: 16144429]
37. Clark CAC, Sheffield TD, Chevalier N, et al. Charting early trajectories of executive control with the Shape School. Dev Psychol. 2013; 49(8):1481–1493. [PubMed: 23106846]
38. Wiebe SA, Sheffield T, Nelson JM, Clark CAC, Chevalier N, Espy KA. The structure of executive function in 3-year-olds. J Exp Child Psychol. 2011; 108:436–452. [PubMed: 20884004]
39. Lee K, Bull R, Ho RMH. Developmental changes in executive functioning. Child Dev. 2013; 84(6): 1933–1953. [PubMed: 23550969]

40. Xu F, Han Y, Sabbagh MA, Wang T, Ren X, Li C. Developmental differences in the structure of executive function in middle childhood and adolescence. PLoS One. 2013; 8(10):e77770. [PubMed: 24204957]
41. Alvarez JA, Emory E. Executive function and the frontal lobes: a meta-analytic review. Neuropsychol Rev. 2006; 16(1):17–42. [PubMed: 16794878]
42. Bebko G, Bertocci MA, Fournier JC, et al. Parsing dimensional vs diagnostic category-related patterns of reward circuitry function in behaviorally and emotionally dysregulated youth in the Longitudinal Assessment of Manic Symptoms study. JAMA Psychiatry. 2013; 71(1):71–80.
43. Casey BJ, Durston S, Fossella JA. Evidence for a mechanistic model of cognitive control. Clin Neurosci Res. 2001; 1:267–182.
44. Ikkai A, Curtis CE. Common neural mechanisms supporting spatial working memory, attention and motor intention. Neuropsychologia. 2011; 49:1428–1434. [PubMed: 21182852]
45. Pavuluri MN, O'Connor MM, Harral EM, Sweeney JA. An fMRI study of the interface between affective and cognitive neural circuitry in pediatric bipolar disorder. Psychiatry Res. 2008; 163(3): 244–255.
46. Scherf KS, Sweeney JA, Luna B. Brain basis of developmental change in visuospatial working memory. J Cogn Neurosci. 2006; 18:1045–1058. [PubMed: 16839280]
47. Booth JR, Burman DD, Meyer JR, et al. Neural development of selective attention and response inhibition. NeuroImage. 2003; 20:737–751. [PubMed: 14568448]
48. Geier CF, Garver K, Terwilliger R, Luna B. Development of working memory maintenance. J Neurophysiol. 2008; 101:84–99. [PubMed: 18971297]
49. Marsh R, Zhu H, Schultz RT, et al. A developmental fMRI study of self-regulatory control. Hum Brain Map. 2006; 27:848–863.
50. Fair DA, Dosenbach NUF, Church JA, et al. Development of distinct control networks through segregation and integration. Proc Natl Acad Sci. 2007; 104:13507–13512. [PubMed: 17679691]
51. Sherman LE, Rudie JD, Pfeifer JH, et al. Development of the default mode and central executive networks across early adolescence: a longitudinal study. Dev Cogn Neurosci. 2014; 10:148–159. [PubMed: 25282602]
52. Sridharan D, Levitin DJ, Menon V. A critical role for the right fronto-insular cortex in switching between central-executive and default-mode networks. Networks. 2008; 105:12569–12574.
53. Chaddock-Heyman L, Erickson KI, Voss MW, et al. White matter microstructure is associated with cognitive control in children. Biol Psychol. 2013; 94:109–115. [PubMed: 23714226]
54. Klingberg T, Forssberg H, Westerberg H. Increased brain activity in frontal and parietal cortex underlies the developmental of visuospatial working memory capacity during childhood. J Cogn Neurosci. 2002; 14:1–10. [PubMed: 11798382]
55. Kharitonova M, Martin RE, Gabrieli JDE, Sheridan MA. Cortical gray-matter thinning is associated with age-related improvements on executive function tasks. Dev Cogn Neurosci. 2013; 6:61–71. [PubMed: 23896579]
56. Clark CAC, Fang H, Espy KA, et al. Relation of neural structure to persistently low academic achievement: a longitudinal study of children with differing birth weights. Neuropsychology. 2013; 27:364–377. [PubMed: 23688218]
57. Nosarti C, Giouroukou E, Healy E, et al. Grey and white matter distribution in very preterm adolescents mediates neurodevelopmental status. Brain. 2008; 131(Pt 1):207–215.
58. Peterson BS, Vohr B, Staib LH, et al. Regional brain volume abnormalities and long-term cognitive outcome in preterm infants. JAMA. 2000; 284:1939–1947. [PubMed: 11035890]
59. Taylor HG, Filipek PA, Juranek J, et al. Brain volumes in adolescents with very low birth weight: effects on brain structure and associations with neuropsychological outcomes. Dev Neuropsychol. 2011; 36:97–117.
60. Volpe J. The encephalopathy of prematurity-brain injury and impaired brain development inextricably intertwined. Semin Pedatr Neurol. 2009; 16:167–178.
61. Woodward LJ, Clark CAC, Bora S, Inder TE. Neonatal white matter abnormalities an important predictor of neurocognitive outcome for very preterm children. PLoS One. 2012; 7(12):e51879. [PubMed: 23284800]

62. Aarnoudse-Moens CS, Duivenvoorden HJ, Weisglas-Kuperus N, Van Goudoever JB, Oosterlaan J. The profile of executive function in very preterm children at 4 to12 years. Dev Med Child Neurol. 2012; 54(3):247–253. [PubMed: 22126188]

63. Aarnoudse-Moens CSH, Weisglas-Kuperus N, van Goudoever JB, Oosterlaan J. Meta-analysis of neurobehavioural outcomes in very preterm and/or very low birth weight children. Pediatrics. 2009; 124(2):717–728. [PubMed: 19651588]

64. Mulder H, Pitchford NJ, Hagger MS, Marlow N. Development of executive function and attention in preterm children: a systematic review. Dev Neuropsychol. 2009; 34(4):393–421. [PubMed: 20183707]

65. Taylor HG, Minich N, Bangert B, Filipek PA, Hack M. Long-term neuropsychological outcomes of very low birth weight: associations with early risks for periventricular brain insults. J Int Neuropsychol Soc. 2004; 10:987–1004. [PubMed: 15803562]

66. Anderson PJ, Doyle LW. Executive functioning in school-aged children who were born very preterm or with extremely low birth weight in the 1990s. Pediatrics. 2004; 114(1):50–57. [PubMed: 15231907]

67. Orchinik LJ, Taylor HG, Espy KA, et al. Cognitive abilities in extremely preterm/extremely low birth weight children in kindergarten. J Int Neuropsychol Soc. 2011; 17:1067–1079. [PubMed: 21923973]

68. Taylor HG, Minich NM, Klein N, Hack M. Longitudinal outcomes of very low birth weight: neuropsychological findings. J Int Neuropsychol Soc. 2004; 10:149–163. [PubMed: 15012835]

69. Baron IS, Kerns KA, Müller U, Ahronovich MD, Litman FR. Executive functions in extremely low birth weight and late-preterm preschoolers: effects on working memory and response inhibition. Child Neuropsychol. 2012; 18(6):586–599. [PubMed: 22122351]

70. Hodel AS, Brumbaugh JE, Morris AR, Thomas KM. Hot executive function following moderate-to-late preterm birth: altered delay discounting at 4 years of age. Dev Sci. 2015; 2:221–234.

71. Tanis JC, Van Braeckel KNJA, Kerstjens JM, et al. Functional outcomes at age 7 years of moderate preterm and full term children born small for gestational age. J Pediatr. 2015; 166:552–558. [PubMed: 25575420]

72. Clark CAC, Woodward LJ. Relation of perinatal risk and early parenting to executive control at the transition to school. Dev Sci. 2015; 18(4):525–542. [PubMed: 25288501]

73. Clark CAC, Woodward LJ, Horwood LJ, Moor S. Developmental of emotional and behavioral regulation in children born extremely and very preter: biological and social influences. Child Dev. 2008; 79(5):1444–1462. [PubMed: 18826535]

74. Luu TM, Ment L, Allan W, Schneider K, Vohr BR. Executive and memory function in adolescents born very preterm. Pediatrics. 2011; 127(3):e639–e646. [PubMed: 21300680]

75. Taylor HG, Margevicius S, Schluchter M, Andreias L, Hack M. Persisting behavior problems in extremely low birth weight adolescents. J Dev Behav Pediatr. 2015; 36:178–187. [PubMed: 25741950]

76. Farooqi A, Adamsson M, Serenius F, Hägglöf B. Executive functioning and learning skills of adolescent children born at fewer than 26 weeks of gestation. PLoS One. 2016; 11:e0151819. [PubMed: 26999522]

77. Bayless S, Stevenson J. Executive functions in school-age children born very prematurely. Early Hum Dev. 2007; 83:247–254. [PubMed: 16837146]

78. Böhm B, Smedler A-C, Forssberg H. Impulse control, working memory and other executive functions in preterm children when starting school. Acta Paediatr. 2004; 93:1363–1371. [PubMed: 15499959]

79. Kulseng S, Jennekens-Schinkel A, Naess P, et al. Very-low-birthweight and term small-for-gestationa-age adolescents: attention revisted. Acta Paediatr. 2006; 95:224–230. [PubMed: 16449031]

80. Marlow N, Hennessy EM, Bracewell MA, Wolke D. for the EPICure Study Group. Motor and executive function at 6 years of age after extremely preterm birth. Pediatrics. 2007; 120(4):793–804. [PubMed: 17908767]

81. Nosarti C, Giouroukou E, Micali N, et al. Impaired executive functioning in young adults born very preterm. J Int Neuropsychol Soc. 2007; 13:571–581. [PubMed: 17521479]

82. Vicari S, Caravale B, Carlesimo GA, Casadei AM, Allemand F. Spatial working memory deficits in children at ages 3–4 who were low birth weight, preterm infants. Neuropsychol. 2004; 18(4):673–678.

83. Baron IS, Erickson K, Abronovich M, Litman F, Brandt J. Spatial location memory discriminates children born at extremely low birth weight and late-preterm at age three. Neuropsychol. 2010; 24:784–797.

84. Jaekel J, Baumann N, Wolke D. Effects of gestational age at birth on cognitive performance: a function of cognitive workload demands. PLoS One. 2013; 8(5):e65219. [PubMed: 23717694]

85. Wehrle FM, Kaufmann L, Benz LD, Huber R, O-Gorman RL, Latal B, Hagmann CF. Very preterm adolescents show impaired performance with increasing demands in executive function tasks. Early Hum Dev. 2016; 92:37–43. [PubMed: 26651084]

86. Espy KA, Stalets MM, McDiarmid MM, et al. Executive functions in preschool children born preterm: application of cognitive neuroscience paradigms. Child Neuropsychol. 2002; 8(2):83–92. [PubMed: 12638062]

87. Sun J, Mohay H, O'Callaghan M. A comparison of executive function in very preterm and term infants at 8 months corrected age. Early Hum Dev. 2009; 85:225–230. [PubMed: 19006652]

88. Woodward LJ, Edgin JO, Thompson D, Inder TE. Object working memory deficits predicted by early brain injury and development in the preterm infant. Brain. 2005; 128:2578–2587. [PubMed: 16150850]

89. Edgin JO, Inder TE, Anderson PJ, Hood KM, Clark CAC, Woodward LJ. J Int Neuropsychol Soc. 2008; 14:90–101. [PubMed: 18078535]

90. Woodward LJ, Clark CAC, Pritchard VE, Anderson PJ, Inder TE. Neonatal white matter abnormalities predict global executive function impairment in children born very preterm. Dev Neuropsychol. 2011; 36(1):22–41. [PubMed: 21253989]

91. Litt JS, Taylor HG, Margevicius S, et al. Academic achievement of adolescents born with extremely low birth weight. Acta Paediatr. 2012; 101:1240–1245. [PubMed: 22812699]

92. Wilson-Ching M, Molloy CS, Anderson VA, et al. Attention difficulties in a contemporary geographic cohort of adolescents born extremely preterm/extremely low birth weight. J Int Neuroopsychol Soc. 2013; 19:1097–1108.

93. Burnett AC, Scratch SE, Lee KJ, et al. Executive function in adolescents born <1000 g or <28 weeks: a prospective cohort study. Pediatrics. 2015; 135:e826–e834. [PubMed: 25802342]

94. Eryigit Madzwamuse S, Baumann N, Jaekel J, Bartmann P, Wolke D. Neuro-cognitive performance of very preterm or very low birth weight adults at 26 years. J Child Psychol Psychiatry. 2015; 56:857–864. [PubMed: 25382451]

95. Pyhälä R, Lahti J, Heinonen K, et al. Neurocognitive abilities in young adults with very low birth weight. Neurology. 2011; 77:2052–2060. [PubMed: 22146921]

96. Kalpakidou AK, Allin MPG, Walshe M, et al. Functional neuroanatomy of executive function after neonatal brain injury in adults who were born very preterm. PLoS One. 2014; 9:1–17.

97. Lawrence EJ, Rubia K, Murray RM, et al. The neural basis of response inhibition and attention allocation as mediated by gestational age. Hum Brain Mapp. 2009; 30:1038–1050. [PubMed: 18412112]

98. Scheef L, Sorg C, Daamen M, et al. Working memory in preterm-born adults: load-dependent compensatory activity of the posterior default mode network. Hum Brain Mapp. 2015; 1137:1121–1137.

99. Baron IS, Weiss BA, Litman FR, Ahronovich MD, Baker R. Latent mean differences in executive function in at-risk preterm children: the delay-deficit dilemma. Neuropsychology. 2014; 28:541–551. [PubMed: 24708045]

100. Ritter BC, Nelle M, Perrig W, Steinlin M, Everts R. Executive functions of children born very preterm—deficit or delay? Eur J Pediatr. 2013; 172:473–483. [PubMed: 23247616]

101. Clark CAC, Woodward LJ. Neonatal cerebral abnormalities and later verbal and visuospatial working memory abilities of children born very preterm. Dev Neuropsychol. 2010; 35(6):622–642. [PubMed: 21038157]

102. Skranes J, Løhaugen GC, Martinussen M, et al. White matter abnormalities and executive function in children with very low birth weight. Neuroreport. 2009; 20:263–266. [PubMed: 19444947]

103. Thompson DK, Lee KJ, Egan GF, et al. Regional white matter microstructure in very preterm infants: predictors and 7 year outcomes. Cortex. 2014; 52:60–74. [PubMed: 24405815]

104. Giménez M, Junqué C, Narberhaus A, et al. Correlations of thalamic reductions with verbal fluency impairment in those born prematurely. Neuroreport. 2006; 17:463–466. [PubMed: 16543807]

105. Lind A, Haataja L, Rautava L, et al. Relations between brain volumes, neuropsychological assessment and parental questionnaire in prematurely born children. Eur Child Adolesc Psychiatry. 2010; 19:407–417. [PubMed: 19821136]

106. Taylor HG, Klein N, Drotar D, Schluchter M, Hack M. Consequences and risks of <1000-g birth weight for neuropsychological skills, achievement, and adaptive behavior. J Dev Behav Pediatr. 2006; 27:459–469. [PubMed: 17164618]

107. Urben S, Van Hanswijck De Jong L, Barisnikov K, et al. Gestational age and gender influence on executive control and its related neural structures in preterm-born children at 6 years of age. Child Neuropsychol. 2015; 7049:1–20.

108. Young JM, Morgan BR, Powell TL, et al. Associations of perinatal clinical and magnetic resonance imaging measures with developmental outcomes in children born very preterm. J Pediatr. 2015; 170:90–96. [PubMed: 26707586]

109. Nosarti C, Rubia K, Smith AB, et al. Altered functional neuroanatomy of response inhibition in adolescent males who were born very preterm. Dev Med Child Neurol. 2006; 48:265–271. [PubMed: 16542513]

110. Treyvaud K, Doyle LW, Lee KJ, et al. Parenting behavior at 2 years predicts school-age performance at 7 years in very preterm children. J Child Psychol Psychiatry. 2015; doi: 10.1111/jcpp.12489

111. McDonald SW, Kingston D, Bayrampour H, Dolan SM, Tough SC. Cumulative psychosocial stress, coping resources, and preterm birth. Arch Womens Ment Health. 2014; 17:559–568. [PubMed: 24948100]

112. Treyvaud K. Parent and family outcomes following very preterm or very low birth weight birth: a review. Semin Fetal Neonatal Med. 2014; 19:131–135. [PubMed: 24252709]

113. Gueron-sela N, Atzaba-poria N, Meiri G, Marks K. The caregiving environment and developmental outcomes of preterm infants: diathesis stress or differential susceptibility effects? Child Dev. 86:1014–1030.

114. Camerota M, Willoughby MT, Cox M, Greenberg MT. Executive function in low birth weight preschoolers: the moderating effect of parenting. J Abnorm Child Psychol. 2015; 43:1551–1562. [PubMed: 25971883]

115. Johnson S, Wolke D, Hennessy E, Marlow N. Educational outcomes in extremely preterm children: neuropsychological correlates and predictors of attainment. Dev Neuropsychol. 2011; 36:74–95. [PubMed: 21253992]

116. Loe IM, Feldman HM, Huffman LC. Executive function mediates the effects of gestational age on functional outcomes and behavior in preschoolers. J Dev Behav Pediatr. 2014; 35:323–333. [PubMed: 24906034]

117. Mulder H, Pitchford NJ, Marlow N. Processing speed and working memory underlies academic attainment in very preterm children. Arch Dis Child Fetal Neonatal Ed. 2010; 95:F267–F272. [PubMed: 20488865]

118. Scott MN, Taylor HG, Fristad MA, et al. Behavior disorders in extremely preterm/extremely low birth weight children in kindergarten. J Dev Behav Pediatr. 2012; 33:202–213. [PubMed: 22245934]

119. Taylor HG, Burant CJ, Holding PA, Klein N, Hack M. Sources of variability in sequelae of very low birth weight. Child Neuropsychol. 2002; 8(3):163–178. [PubMed: 12759832]

120. Rose SA, Feldman JF, Jankowski JJ, Van Rossem R. The structure of memory in infants and toddlers: an SEM study with full-terms and preterms. Dev Sci. 2011; 14:83–91. [PubMed: 21159090]

121. Wong T, Taylor HG, Klein N, et al. Kindergarten classroom functioning of extremely preterm/ extremely low birth weight children. Early Hum Dev. 2014; 90:907–914. [PubMed: 25448780]
122. Hays B, Sharif F. Behavioural and emotional outcome of very low birth weight infants–literature review. J Matern Fetal Neonatal Med. 2009; 22(10):849–856. [PubMed: 19521926]
123. Ni T-L, Hugan C-C, Guo N-W. Executive function deficit in preschool children born very low birth weight with normal early development. Early Hum Dev. 2011; 87:137–141. [PubMed: 21194855]
124. Johnson S, Gilmore C, Gallimore I, Jaekel J, Wolke D. The long-term consequences of preterm birth: what do teachers know? Dev Med Child Neurol. 2015; 57(6):571–577. [PubMed: 25586544]
125. Loe IM, Chatav M, Alduncin N. Complementary assessments of executive function in preterm and full-term preschoolers. Child Neuropsychol. 2015; 21(3–4):331–353. [PubMed: 24754400]
126. Feldman R, Rosenthal Z, Eidelman AI. Maternal-preterm skin-to-skin contact enhances child physiologic organization and cognitive control across the first 10 years of life. Biol Psychology. 2014; 75:56–64.
127. Landry SH, Miller-Loncar CL, Smith KR, Swank PR. The role of parenting in children's development of executive processes. Dev Neuropsychol. 2002; 21(1):15–41. [PubMed: 12058834]
128. Treyvaud K, Anderson VA, Lee KJ, et al. Parental mental health and early social-emotional development in children born very preterm. J Pediatr Psychol. 2010; 35(7):768–777. [PubMed: 19955253]
129. Bryck RL, Fisher PA. Training the brain : practical applicatins of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science. Am Psychol. 2012; 67:87–100. [PubMed: 21787037]
130. Bierman KL, Nix RL, Greenberg MT, Blair C, Domitrovich CE. Executive functions and school readiness intervention: impact, moderation, and mediation in the Head Strat REDI program. Dev Psychopathol. 2008; 20:821–843. [PubMed: 18606033]
131. Blair C, Raver CC. Closing the achievement gap through modification of neurocognitive and neuroendocrine functions: results from a cluster randomized controlled trial of an innovative approach to the education of children in kindergarten. PLoS One. 2014; 9(11):e112393. [PubMed: 25389751]
132. Rueda M, Rothbart M, McAndliss B, Saccomanno L, Posner M. Training, maturation, and genetic influences on the development of executive attention. Proc Natl Acad Sci. 2005; 102:14931–14936. [PubMed: 16192352]
133. Grunewaldt KH, Løhaugen GCC, Austeng D, Brubakk AM, Skranes J. Working memory training improves cognitive function in VLBW preschoolers. Pediatrics. 2013; 131:e747–754. [PubMed: 23400616]
134. Løhaugen GCC, Antonsen I, Håberg A, et al. Computerized working memory training improves function in adolescents born at extremely low birth weight. J Pediatr. 2011; 158:555–561. [PubMed: 21130467]
135. Melby-Lervåg M, Hulme C. Is working memory training effective? A meta-analytic review. Dev Psychol. 2013; 49:270–291. [PubMed: 22612437]
136. Shipstead Z, Redick TS, Engle RW. Is working memory training effective? Psychol Bull. 2012; 138:628–654. [PubMed: 22409508]
137. Feldman R. The development of regulatory functions from birth to 5 years: insights from premature infants. Child Dev. 2009; 80:544–561. [PubMed: 19467010]
138. Johnson MH. Executive function and developmental disorders: the flip side of the coin. Trends Cogn Sci. 2012; 16:454–457. [PubMed: 22835639]
139. Heinonen K, Eriksson JG, Lahti J, et al. Late preterm birth and neurocognitive performance in late adulthood: a birth cohort study. Pediatrics. 2015; 135:e818–e825. [PubMed: 25733746]
140. Lawrence V, Houghton S, Douglas G, et al. Executive function in ADHD: a comparison of children's performance during neuropsychological testing and real-world activities. J Atten Disord. 2004; 7(3):137–149. [PubMed: 15260171]

141. Litt JS, Taylor HG, Klein N, Hack M. Learning disabilities in children with very low birthweight: prevalence, neuropsychological correlates, and educational interventions. J Learn Disabil. 2005; 38:130–141. [PubMed: 15813595]

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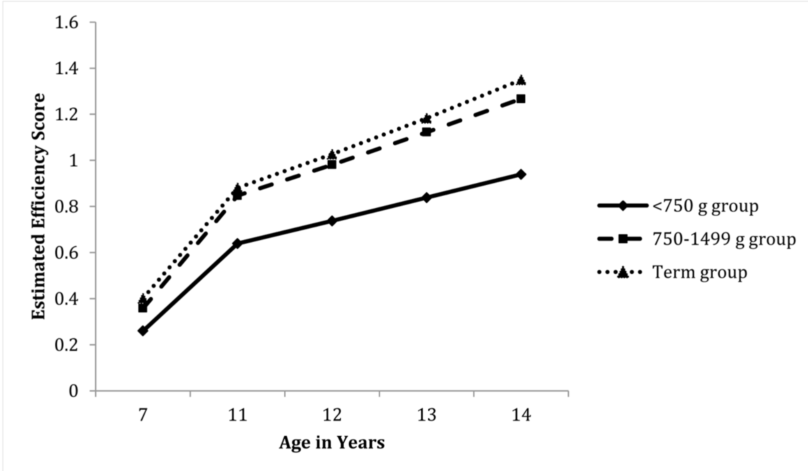

Figure 1.

Findings from a longitudinal study of children of varying degrees of prematurity compared to a Term control group on the Contingency Naming Test, a test involving rapid naming of colored shapes that places demands on working memory and cognitive flexibility. The plot is based on findings reported in by Taylor et al.[68] Results from a mixed model analysis revealed a significant group x age interaction, indicating slower age-related improvements in test scores in the <750 g group compared to Term controls. Performance was measured in terms of an efficiency score that took both naming errors and time into account.

Table 1

Examples of research tasks used to assess different components of executive function in children and adults

Executive Process	Tasks used with adults	Tasks used with young children
Working memory	*Reading span task*[23]: Participants read a series of sentences. They are instructed to repeat the final word from each sentence after reading increasingly lengthening sentence sequences. The task reflects the ability to maintain and update verbal information in working memory.	*A-not-B task*[24]: Infants view and retrieve a toy hidden in location A over a series of trials. The toy is then transferred to location B and the infant must update his/her representation and search strategy to successfully retrieve the toy from the new location.
Cognitive flexibility/Switching ability	*Wisconsin card sorting task*[25]: Participants sort cards according to different dimensions (e.g., color, shape, number) and must infer the sorting rule according to feedback. Task scores reflect the participant's ability to remember the current sorting rule, abstract a new rule and flexibly switch between rules.	*Standard dimensional change card sort*[26]: Children are instructed explicitly to sort cards that vary by color and shape (e.g., blue rabbits, blue houses, red rabbits, red houses) along one dimension. During the post-switch phase, they must switch to sorting by the other dimension. The majority of toddlers perseverate on the first dimension, making this an appropriate measure of cognitive flexibility for preschoolers.
Inhibitory control	*Stop-signal task*[27]: Participants press a button in response to a visual stimulus as quickly as possible. On occasional trials, participants hear a tone after trial onset and are required to withhold the button press response. By manipulating the time between trial onset and the stop signal, the task determines the minimum warning time required for a participant to inhibit his/her response.	*Go/no-go task*[28]: Children are instructed to press a button in response to one stimulus (e.g., a fish) and withhold the response to another, infrequent stimulus (e.g. a shark). The task assesses the ability to withhold a prepotent motor response.