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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.

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 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 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

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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 the color of the word "red" when the word is printed in green ink). Other examples of tasks that are used to assess EF are listed in the Table, 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.

Table – 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.