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Executive Functioning During Infancy and Childhood

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Introduction

Executive functions refer to a set of cognitive processes that support the regulation of thoughts, emotions and behaviours. Executive functions help us to achieve goals in our daily lives, whether planning a vacation, controlling anger or multi-tasking. They develop dramatically during infancy and childhood,[1,2] and predict later success in school, health and income.[3] They are also trainable under certain conditions.[4] At the same time, executive functions are highly heritable,[5] meaning that genetic differences between individuals contribute to differences between individuals in executive functions. Moreover, these differences are stable across development:[6,7] Low executive functioning in childhood predicts low executive functioning decades later. Impairments in executive functions are observed in children from backgrounds of low socioeconomic status[8] and in a variety of clinical disorders, including Attention Deficit Hyperactivity Disorder,[9] autism[10] and depression.[11]

Subject

Limits in executive functioning can lead children to seem stubborn or mischievous, like when they insist that they don’t need a jacket to go play in the snow, or reach for a cookie despite being able

to repeat the instruction that they cannot have one until after dinner. Executive functions are predictive of later life outcomes. Individual differences in executive functioning at kindergarten entry predict later academic achievement, and may be more critical to early success than familiarity with numbers and letters.[12-14] Self-regulatory behaviours predict social skills, relationships with teachers and peers, school engagement, health, wealth and criminality later in life.[3,15] Under certain conditions, executive functions may be trainable. Preschool programs developed to improve cognitive and behavioural school readiness have led to improvements in executive functions, as have a variety of interventions in primary school.[16-18] Aerobics, martial arts, yoga, dance and targeted game play interventions have also been associated with executive function improvements in children.[4] Training interventions may help to reduce or eliminate the executive function deficits observed in children from low-socioeconomic status backgrounds,[19,20] though ecological studies examining population-level intervention effects are, as yet, forthcoming.

Problems

Executive functions are complex, leading to challenges in measuring and in tracking developmental changes in them. They span a variety of higher-level cognitive processes, including planning, decision-making, maintaining and manipulating information in working memory, monitoring the environment for goal-relevant information, shifting from one task to another, and inhibiting unwanted thoughts, feelings and actions. In addition, these higher-level processes rely upon lower-level cognitive, perceptual and motor processes, making it difficult to measure executive functions purely.[21,22] For example, a person's ability to resist chocolate while on a diet reflects not only their ability to inhibit the urge to eat it, but also their hunger and reasons for dieting. This difficulty in measuring executive functions purely also leads to difficulty in measuring changes in them across development. Lower-level processes are developing as well as executive functions, making it challenging to design executive function measures that can be used with people of a variety of ages. For example, changes in inhibition from infancy to adulthood could not be tracked by measuring changes in the ability to stick to a diet! As a result, researchers have often used different measures of executive functioning with different age groups, for example, measuring infant inhibition in the context of maintaining attention in the face of distractors,[23] and children's inhibition in the context of a Simon Says type game, where an adult's behaviours are usually imitated but sometimes the opposite should be done instead.[24] Differences across measures make it difficult to draw firm conclusions about developmental changes in executive functioning.

Research Context

The study of executive functions and their development is advancing rapidly. The use of neuroscience methods, including *functional neuroimaging*, *electroencephalography*, and computational models, are providing insights into the brain changes that support the development of executive functioning.[2,25-27] To address the issue of task impurity, researchers have developed sets of tasks that share executive functioning demands but differ in other ways. For example, a set of inhibition tasks might include one task that requires children to focus their gaze on something and inhibit the urge to look toward something distracting, and another task that requires children to say the color of a word on a screen (e.g., the word “green” printed in blue ink) and refrain from reading the word itself. Statistical techniques can be used to extract what is common in performance across those tasks, providing a more pure measure of executive functions.[5] To address the difficulty in comparing executive functioning across ages, researchers have developed measures that can be changed slightly to manipulate executive function demands, while keeping all other aspects of the task the same. For example, in a task where children are required to inhibit the urge to look toward something distracting, the number of distracting things might be increased with age. Such measures provide sensitivity across a broad range of ages, allowing researchers look at quantitative changes in performance to track executive function development.[1]

Key Research Questions

1. What developments are observed in executive functions during infancy and childhood?
2. What drives these developments?
3. Why do executive functions predict later functioning and general intelligence?

Recent Research Results

The component processes of executive functioning appear to become more specialized during development: in early childhood, children use the same cognitive processes in all situations that require control, whereas from middle childhood onwards, those processes progressively specialize into components such as suppressing a usual action or switching between multiple tasks.[21,28,29] Executive functioning also becomes more self-directed (so that children rely progressively less on other people), and shifts from reactive control (with children adjusting to events as they occur) to proactive control (with children anticipating and preparing for upcoming events).[2] For instance,

younger children may be prone to study for a school exam at the last minute and only when prompted by parents, whereas older children may start to study ahead of time in anticipation of potential issues. Changes in executive functioning are driven in part by an increasing ability to keep appropriate goals in mind (e.g., to keep studying despite the temptation to play video games), but also by children's increasing ability to monitor their environment to determine which behaviours are appropriate (e.g., studying today is important for tomorrow's exam).[30,31] These improvements are accompanied by stronger activity with age in a broadly distributed neural network that spans the *prefrontal cortex,* the *parietal cortex,* and the *basal ganglia,* with increased connectivity among these regions and variations in patterns of activation across development.[25,27]

Research Gaps

To date, we have limited understanding of gene-environment interactions in executive functioning: how environmental experiences influence the expression of genes that influence executive functions, and how genetic variables influence environmental characteristics that may impact executive functions.[5] In addition, research has primarily emphasized quantitative changes in the efficiency of the processes underlying executive functioning, assuming that all children use the same processes or strategies which are applied more successfully with age. Yet, strategies may change with age and across children the same age, potentially giving rise to different developmental pathways of executive functioning. Strategy variability largely remains to be explored.[32,33] Finally, more work is needed to fully understand which brain changes support changes in executive functioning, particularly during early childhood, and how such brain changes lead to changes in executive functioning.[2]

Conclusions

Although executive functions are complex and difficult to measure, significant progress has been made in understanding these fundamental higher-level cognitive processes during infancy and childhood – how they change during development, how they influence behaviour, what aspects of later life outcomes they predict, and what kind of experiences might influence this course of development. This work has highlighted the essential role of executive functions in children's development. Many questions remain to be addressed through further behavioural and neuroscience research. Such questions include how individual children differ in their developmental trajectories of executive functioning and the consequences of such variation, why executive functions predict later life outcomes, and how genetic and environmental influences and

resulting brain changes lead to the dramatic executive function improvements observed across infancy and childhood. A better understanding of executive function development will be crucial to the improvement of training programs, intervention strategies, and early diagnostic tools designed to maximize children's potential for later academic achievement and success.

Implications for Parents, Services and Policy

When children do things they are not supposed to, or seem to not be listening, they are not necessarily being stubborn or mischievous. Even when children are highly motivated to behave appropriately, limits in their executive functioning can hinder their ability to do so. When unaddressed, deficits in executive functions predict decreased academic achievement, and may help to explain persistent gaps in educational achievement between high- and low-socioeconomic status students. Policymakers faced with limited resources may find it difficult to choose between available interventions aiming to improve executive functions, however. Data comparing the efficacy of various interventions are limited, interventions may impact children of different ages and developmental trajectories differently, and few programs have been scaled up from demonstration studies to system-wide interventions. Improvements in early diagnostic tools and efforts to determine the long-term impacts of interventions in early and middle childhood will help to clarify optimal timing and administration of interventions.

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