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Development



Executive functions

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Synthesis

How important is it?

Executive functions are the cognitive abilities needed to control and regulate our thoughts, emotions and actions. A distinction is sometimes made between the “cool” component of executive functions which strictly involves cognitive skills (e.g., the ability to do mental arithmetic), and the “hot” component, which reflects the ability to regulate emotions (e.g., being able to control anger).

Executive functions can be divided into three broad categories of skills:

- Self-control: The ability to resist doing something tempting in order to do the proper thing. This ability helps children pay attention, act less impulsively and stay focused on their work.
- Working memory: The ability to keep information in mind where it can be manipulated. This skill is necessary to perform cognitive tasks such as relate topics to one another, mental calculation, and decide what needs to get done in order of priority.
- Cognitive flexibility: This involves creative thinking and flexible adjustments to changing requests. This ability assists children in using their imagination and creativity to solve problems.

Executive function abilities are critically important for development as illustrated by the fact that early differences in executive functions longitudinally predict important developmental outcomes, including academic achievement, health behaviours and social adjustment.

What do we know?

Executive functions take time to develop to their full potential, and this is partly explained by the slow maturation of *prefrontal cortex*. Changes in executive functions are apparent when children become able to remind themselves what the important goals are (e.g., finish one’s homework rather than watch television). Improvements in executive functions are also seen when children develop the ability to analyze their environment to decide what is the appropriate plan of action (e.g., studying tonight is crucial for success in tomorrow’s exam). Underdeveloped executive

functions may explain why young children often appear hard-headed when refusing to follow logical instructions such as putting on a hat in the winter. Children from poor economic background are particularly at risk for experiencing executive function difficulties.

Given the long maturation process of executive function skills, children are acutely sensitive to early experiences that can either hinder or boost their abilities. Stress, for instance, can be so damaging to a young child's executive functions that it can lead to a misdiagnosis of ADHD. On the other hand, enhancing experiences, such as a positive parent-child relationship, can protect children against the negative effect of stressful circumstances, such as living in poor economic conditions, and consequently improve executive functioning. Children of responsive parents who use gentle rather than harsh discipline and who are supportive of their child's autonomy also tend to have better executive function skills.

High executive functioning is linked to several positive outcomes such as competency in the social, emotional and academic domains. In fact, they predict early school success better than intelligence, early numeracy and literacy. Executive function skills appear to enable children to navigate their constantly changing environment, which may be especially key for children developing in high-risk environments. Executive function efficiency predicts health, economic prosperity and few criminal acts in later life. Specific components of executive functions are also responsible for children's ability to understand other people's minds. For instance, response conflict-executive functioning (RC-EF) is strongly predictive of children's false belief understanding, the notion that others can have beliefs about the world that are different than one's own, which is a required skill for successful social interactions.

While there are several benefits to strong executive function abilities, poor executive functioning is characteristic of a number of disorders such as ADHD, behaviour problems, learning difficulties, autism and depression. Early problems with executive functions are also likely to persist throughout childhood and adolescence.

What can be done?

There are several benefits to helping preschool children improve their executive function skills. Intervention programs focusing on executive function training are efficient at enhancing children's school success and socio-emotional skills, and can lead to changes in brain circuitry. Early intervention may also attenuate the rate and the difficulties associated with disorders such

as ADHD and behaviour problems. Executive function training is inexpensive and can be implemented in the regular classroom with children as young as 4 or 5 years of age. Modifications to existing early childhood curricula should include enjoyable and challenging activities that focus on self-regulation. Yoga, music, aerobics, dancing, meditation, story-telling, martial arts are all examples of activities that can help improve core executive function abilities. In the classroom, children should engage in more active learning and small-group activities, and spend less time in large group activities. Children with better executive functions require less negative interventions from teachers, which helps create a stress-free environment that further nurtures the development of executive functions. Young children should also be encouraged to participate in elaborate forms of play, such as social pretend play where they learn to take on roles and adapt to ever-changing plot.

It is also essential to understand that executive function skills are acquired gradually through the years and that even a highly motivated child can struggle with instructions such as not eating a cookie before supper, or concentrating for a long period of time.

Brain Development and Executive Functioning

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Introduction

Executive functions are processes that support many everyday activities, including planning, flexible thinking, focused attention and behavioural inhibition, and show continued development into early adulthood.[1,2] One important backdrop to the development of these psychological abilities is the structural and functional development of the brain.[3,4,5,6] Among the slowest developing brain regions is the prefrontal cortex, a large expanse of cortex located in the front half of the brain. Remarkably, this region of the brain continues to develop into the third decade of life.[7,8] Brain imaging research[9,10] and studies of patients with brain damage[11,12,13] suggest that the prefrontal cortex is vital for controlling attention, thinking and behaviour, in part because it bridges perceptual, emotional and motor control centres located elsewhere in brain. The fact that prefrontal cortex is both slow to develop[14,15] and important for executive control has led to the suggestion that the development of executive functioning is closely related to the maturation of the prefrontal cortex.[16,17,18] One implication is that basic everyday challenges, such as not playing with a forbidden toy, will be difficult even for normally-developing children.

Subject

Understanding that the prefrontal cortex is important for behavioural self-regulation and develops gradually may provide insight into why, for example, children have difficulty: (a) stopping one activity and switching to a new one; (b) planning ahead; (c) doing more than one thing at a time; (d) concentrating for long periods of time; and (e) foregoing immediate rewards. Findings from developmental cognitive neuroscience research suggests these behaviours are a normal part of growing up and are rooted to some degree in how the brain works at this stage in life.

Problems

Understanding precisely how the development of the prefrontal cortex contributes to advances in executive functioning is extremely challenging. First, executive functions are difficult to precisely define and measure, in part because core concepts such as inhibition and cognitive flexibility actually do more to describe than explain behaviour. Second, it is unclear whether processes involved in regulating one kind of behaviour, such as language, are the same as those involved in regulating other kinds of behaviour, such as the emotions. Third, tasks that are appropriate for testing executive functioning at one age will not typically be suitable for testing executive functioning in older children. This makes it difficult to compare executive functioning in children of different ages. Ultimately though, developmental cognitive neuroscientists are interested in linking age-related changes in executive functioning with developmental changes in brain function. To achieve this, it is necessary to not only adequately define and measure executive functioning, but to simultaneously collect a direct measure of brain function. One approach is functional magnetic resonance imaging (or fMRI), a safe and relatively non-invasive means of probing changes in brain activity that occur as people perform certain tasks. While viable and safe for use even with newborn infants,[19,20] fMRI requires that participants remain very still for at least 5 to 10 minutes while the images are acquired. Abrupt movements 5 to 10 mm can render images noisy and virtually uninterpretable. Complicating matters further, if young children perform the prescribed tasks differently than older children, it becomes impossible to know whether age-related differences in patterns of brain activity relate solely to differences in the age of the participants or additionally to differences in the way younger and older children performed the tasks. Put simply, instructing 7-year-olds to perform a task in the way 4-year-olds do could, in principle, cause patterns of brain activity in 7-year-olds to look indistinguishable from those observed in 4-year-olds. To mitigate these problems, researchers are developing new imaging protocols that can be administered quickly and do not require children to perform a task. In these so-called resting-state scans, children simply lay still for as little at five minutes with their eyes open.[21] Resulting images are used to probe for age-related changes in “intrinsic” patterns of cortical connectivity, which then can be associated with measures of executive functioning collected outside the MRI scanner.

Research Context

Findings from fMRI studies of executive functioning development paint a fascinating but complex picture. Some studies, for example, report that younger children show less prefrontal cortex (PFC) activity in the context of executive function tasks than do older participants, findings that

are consistent with the intuition that as a brain region functionally develops, it shows more robust activity and executive functioning improves.[22,23] Other findings suggest a slightly more complicated story, insofar as some regions of PFC exhibit increasing activity with increasing age, while others show decreasing activity with increasing age.[24,25,26] One interpretation of this pattern is that early in life, executive functioning is associated with weak but diffuse PFC activity, whereas later in development, executive functioning is associated with robust but focal PFC activity.[26] Thus, at the centre of a developing region, activity increases with age, whereas in the surround, activity decreases with increasing age. Another interpretation is that certain regions within PFC become more efficient with increasing age. Thus, early in development, these regions need to work very hard to support a certain level of executive functioning performance. However, later in development when these regions function more efficiently, they can support a comparable level of executive functioning performance with less energy expenditure. Clearly, more research is required to clarify this complex picture.

One consistent finding from developmental fMRI investigations of executive functioning performance is that there are many additional regions outside of the PFC linked to the development of executive functioning performance, including anterior cingulate, anterior insula, parietal and motor cortices.[27,28] One interpretation of this evidence is that executive functioning performance tasks are very complex and involve many different subprocesses such as holding instructions in mind,[27,29,30] attending to some stimuli and ignoring others,[22] planning and executing motor responses,[26] and evaluating performance feedback. It is possible then that executive functioning tasks are associated with activity in many brain regions because the tasks themselves involve many different subprocesses, each of which is associated with activity in a different brain region. If this is true, then the challenge moving forward is to identify which subprocesses are subject to age-related change, and to link these changes with changes in the function of specific brain regions. A second interpretation is that PFC does not function independently, but forms part of a broader, functionally homogenous, network. On this view, regardless of whether a participant is holding instructions in mind, planning a response, or evaluating feedback, robust activity will be observed throughout the entire network. If this is true, then the challenge moving forward is to identify how the organization of the larger network changes over development. Possibilities include changes in the regions comprising the larger network as well as changes in the number and strength of connections between constituent regions.

Key Research Questions

1. What are the constituent processes underlying executive functioning task performance?
2. Are different executive functioning's uniquely linked to different brain regions?
3. How do changes in brain function contribute to changes in executive functioning?

Recent Research Results

Recently, researchers have begun examining developmental changes in brain networks thought to be important for executive functioning, by examining changes in connections between PFC and other regions commonly associated with executive functioning such as the parietal, cingulate and insular cortices.[28] As these networks can be observed and measured even while participants are at rest, many recent studies have used so-called resting-state fMRI to probe the organization of cognitive control networks at different ages.[31,32] Initial findings suggested widespread network reorganization of over development, with new long-range connections forming and pre-existing short-range connections being taken away as children grow older.[33] More recent evidence has called these initial findings into question, and suggests the re-organization of executive functioning networks over development may be less pronounced than originally thought.[34] However, despite these initial missteps, the study of network organization over development continues to attract attention as researchers increasingly recognize that brain regions work together to realize high-level thoughts and actions.

Research Gaps

Perhaps the most significant research gap in fMRI research on the development of executive functioning is evidence from longitudinal studies. Unlike cross-sectional studies, in which one group of younger children is compared with a different group of older children, longitudinal studies compare the same group of children at different ages. Needless to say, longitudinal studies are very expensive, take a long time to conduct, and can be very risky, which is the reason why so little longitudinal evidence currently exists. Still, longitudinal designs afford a number of important advantages over cross-sectional designs. First, whenever two groups of children of different ages are compared, there are many factors that could potentially differ between the groups beyond age, including differences in intelligence, temperament/personality, and socio-economic status, to name only a few. Given that each of these factors is related to executive functioning, inferences concerning the importance of age for explaining group

differences in patterns of brain activation become tenuous. Second, an important goal of developmental cognitive neuroscience is to identify early patterns of psychological and neural organization that predict future states, both positive (e.g., intellectual and social well-being) and negative (e.g., psychopathology). Identifying these patterns is best achieved when the same group of children is followed repeatedly over time until the outcome of interest (e.g., giftedness, addiction, risky sexual behaviour, etc.) is observed in some children. Only then can one go back and see which brain or behavioural measure collected earlier in time successfully predict future outcomes.

Conclusions

The brain takes the first two decades of life to develop to adult levels. During this time, different regions of the brain develop at different rates. Alongside these regional changes, the connections between brain regions also develop gradually over the course of childhood and adolescence. In conjunction with these developments in brain structure and function are advances in the ability to perform executive functioning tasks. Children show gradual improvements in their ability to plan ahead, to switch between tasks and to inhibit a response when instructed to do so. The study of brain networks and their development may offer a useful avenue for quantifying the relationship between brain development and the maturation of executive functioning. The frontal and parietal cortices need to communicate in order to effectively perform executive functioning tasks. Effective communication between these regions is not fully developed until late adolescence, and this may explain why executive functioning abilities do not mature until late in the second decade of life.

Implications for Parents, Services and Policy

We need to remember that children’s brains are a work in progress. Whether we measure, grey matter thickness, white matter volume, synaptic density, or any other anatomical feature of the brain, continued change will be observed well into early adulthood. These changes will obviously impact a child’s cognitive functioning, and this will be particularly true of executive functioning, given the complexity of the processes involved. Given the importance of executive functioning for academic achievement and social well-being, identifying problems in cognitive and behavioural self-regulation early-on is clearly important. At the same time, all young children will struggle to plan ahead, resist temptations, regulate their emotions and stay on task: it’s just the way the brain works at this age.

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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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Executive Function and Emotional Development

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Introduction

Emotional development involves increased ability to feel, understand and differentiate progressively more complex emotions, as well as the ability to self-regulate them in order to adapt to the social environment or to accomplish present or future goals. Often, children face situations where they must select among competing options, such as finishing homework before playing or eating a snack now as opposed to saving room for a healthier meal. In making such decisions, they need to reconcile the conflict between competing choices available in the context with a specific set of expectations and rules, as well as to regulate impulses for immediate gratification in the service of a choice that is less immediate and automatic. This sort of behavioural and cognitive control is related to the concept of executive functions. Executive function refers to multidimensional cognitive control processes that are characterized by being voluntary and highly effortful. They include the ability to evaluate, organize and achieve goals, as well as the capacity to flexibly adapt behaviour when confronted with novel problems and situations. Evidence from cognitive development and developmental cognitive neuroscience has shown that the development of emotion regulation is strongly supported by several core executive functions, such as attention control, inhibition of inappropriate behaviours, decision making and other high cognitive processes that take place in emotionally demanding contexts.[1,2]

Subject

As humans are predominantly social, understanding emotions in oneself and others is an important skill to have, and a good part of the brain is devoted to that effort.[3] Basic emotions, such as happiness or fear differ from the so-called moral emotions (e.g., shame, guilt, pride, etc.), that arise in social interactions, where a normative or ideal behaviour is either explicitly or implicitly established. Understanding and managing moral emotions requires internalization of norms and moral principles shared by the community. It is also necessary to perceive and understand other people's emotions (empathy) and make attributions of their mental states

(theory of mind), including understanding of their beliefs and attitudes. As such, emotional and social development are tightly linked to one another. Another key component of emotional development, namely emotion regulation, is not less crucial to socialization. In social activities (e.g., being at school), it is often necessary to control emotional reactions, either positive (e.g., excitement) or negative (e.g., frustration) in order to accommodate to norms and goals. Therefore, the development of executive control is central to emotion regulation.

Problems

Executive function is often considered a domain-general of cognitive function. This means that it is involved in regulating all sorts of behaviours, such as those involving language, memory, reasoning, etc. However, some authors have suggested that emotional, social and motivated behaviour (e.g., deciding whether to eat a piece of cake or to hug someone we love) may be harder to control and might even require a different kind of mechanism as compared to emotionally-neutral conditions (e.g., deciding whether five is an even or odd number). Some authors have established a distinction between “cool” (purely cognitive) and “hot” (affective) aspects of executive function.[4] Thus, in goal-directed problem-solving, executive function and emotion regulation bear a reciprocal relation. However, the particular requirements for emotion regulation will depend on the motivational significance of the problem and whether the problem itself is hot or cool.[1]

Research Context

The multidimensional nature of the executive function construct contrasts with the absence of a specific agreement on a gold-standard test of executive functions despite the highly structured nature of the tasks typically used to examine different functions separately. A variety of laboratory tasks are thus used to measure different executive functions, some of which have been adapted from those used with adults. A general distinction can be made between cool executive function and hot executive function tasks, depending on whether the task involves dealing with emotionally-relevant information or not.[5] Within this general categorization, tasks can be also divided according to the particular function they target, for example, working memory, inhibitory control or mental flexibility. However, given the protracted development of executive function throughout childhood, a wide variety of tasks are available which are appropriate for children of a given age range or ability level.[6]

Key Research Questions

1. Is emotional development supported by maturation of executive function skills? How is the development of key aspects of emotional development (e.g., empathy, theory of mind, internalization of moral principles, etc.) related to maturation of the *prefrontal cortex*?
2. What factors determine the development of executive function skills?
3. Are individual differences in the development of executive function and emotion regulation determined by genes, or are they rather related to experience?
4. Is it possible to foster the development of executive function by means of educational interventions? If so, would enhanced executive function turn into better emotion development?

Recent Research Results

Evidence from multiple studies indicates that maturation of aspects of executive functioning, such as inhibitory control and executive attention, are strongly related to increased emotional understanding (in oneself and others) and regulation. Preschool children's performance on laboratory tasks measuring inhibitory control significantly correlates with their ability to regulate their emotions.[7,8] Also, children with higher attention control abilities tend to cope with anger by using non-hostile verbal methods rather than overt aggressive methods.[9] Higher effortful control also correlates positively with empathy.[10] To display empathy toward others requires interpretation of their signals of distress or pleasure. In fact, the ability to distinguish between mental states of oneself and others (Theory of Mind, ToM), which is another central cognitive component of empathy,[11] is strongly associated with individual differences in effortful and inhibitory control.[12] However, whether ToM is directly associated with more general emotion regulation skills during early development is still under debate.[13] Additionally, individual differences in executive control are associated with the development of conscience, which involves the interplay between experiencing moral emotions and behaving in a way that is compatible with rules and social norms.[14] In this context, internalized control of behaviour is greater in children high in effortful control.[15] The common interpretation is that effortful control provides the attentional flexibility required to link moral principles, feelings and actions.

In addition to these studies, current lines of research are investigating the factors, both educational and constitutional, that influence the development of executive function. Training

studies of different executive functions in preschool and school-aged children have showed direct benefits on the trained abilities, including executive attention,[16,17] fluid reasoning,[18,19,20] working memory[21,22,23] and cognitive control.[24]

Research Gaps

There are future research avenues that have the potential to shed further light on executive functions and emotional development. Although cross-sectional studies can be very informative, longitudinal research is needed to rule out possible effects due to individual variance across age groups. Thus, longitudinal studies can provide important insights regarding typical and atypical cognitive and emotional development.[25] Another important but still unresolved question is to what extent educational interventions designed to foster executive function can produce stable changes in the efficiency of this system, both at the structural and functional levels, throughout development. Some studies have shown benefits of executive function training at the level of brain function during development,[16,17,22,23] which are still observable a few months later without further training.[16] However, more research is needed to further characterize the benefits of training over time, and whether benefits of executive function training transfer to emotion regulation skills.

Conclusions

Emotional development involves increased understanding of emotions in oneself and others as well as increased ability to regulate emotions based on current goals and socially-shared rules. Changes in emotional function are recognized as playing a critical role on social adjustment and school competence.[26,27] Adaptive development of emotion is linked to child well-being, whereas difficulties with emotion regulation are related to mood disruptions and behavioural problems.[27,28] Emotional development is constructed from a variety of cognitive skills, including the ability to flexibly regulate behaviour in a voluntary, effortful, mode (executive function), which strongly depends on maturation of the frontal lobes.[29] Cognitive and emotion regulation appear to develop in concert, showing a strong development during the preschool period and a more protracted developmental course during late childhood and adolescence.[30]

Implications for Parents, Services and Policy

Increasing evidence suggests that executive function can be enhanced through cognitive training and that such interventions have the potential to enhance the efficiency of brain systems

underpinning behavioural and emotional regulation skills in children[16] as well as in adults.[23,31,32] Recent research also shows that the development of executive control is affected by environmental factors, such as parenting and education. The quality of parent-child interactions during early childhood appears to promote the development of executive function later on. Parental attitudes such as warmth, responsiveness and gentle discipline, which are related to secure parent-child attachment and positive mutuality, are related to advanced executive function skills in the child.[33] Likewise, classroom curricula that focus on teaching regulation skills are shown to significantly increase the development of executive control at preschool ages.[24] Plasticity of the neurocognitive system underlying cognitive and emotional regulation could be related to its extended maturation during the first two decades of life. Importantly, the susceptibility of this neurocognitive system to be influenced by a wide range of experiences provides multiple opportunities to promote children's social and emotional competence. Research-based data of the type summarized in this paper must encourage policy makers to promote the use of educational programs that include curricula directly addressing socio-emotional competence.

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The Relation between Executive Functioning and Social Cognition

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Introduction

To make sense of and predict the behaviour of those around us, we use a "theory of mind" – an understanding that peoples' actions are caused by idiosyncratic mental states like beliefs, desires, and intentions.[1] For instance, imagine you see a friend grab a glass from the cupboard and head towards the fridge. No matter what your own favorite drink is, you should expect your friend to search for and retrieve the drink that she likes best. Similarly, imagine that your friend tells you she's hungry and then heads towards a kitchen cupboard that you yourself know is empty. You can make sense of your friend's actions by reasoning that she probably believes that the cupboard has food in it, and is acting accordingly. In these examples, being able to decipher your friend's mental states (i.e., what she desires and believes) allows you to both explain and predict her actions.

Understanding the development of a theory of mind has been a main topic of research over the past 20 years. Within this framework, researchers have been particularly interested in children's understanding of false beliefs – instances in which someone holds a belief about the world that differs from how the world really is. In one task that researchers often use to measure false belief understanding, children are shown a character (e.g., Sally) hide an object in one location and leave the scene. In Sally's absence, the object is moved to an alternative location. Sally then returns, and children are asked where she will look for the object. In order to pass this task, children must recognize that Sally has a false, outdated belief about the object's wherabouts, and will search for it where she (falsely) believes it to be (i.e., in the location where she left the object before leaving). Correct performance on this task typically develops between 3 and 5 years of age, around the same time as a number of related real-world social-cognitive skills, including pretending,[2] lying,[3] playing games like hide-and-seek,[4] keeping secrets,[4] developing peer relationships,[5] and understanding moral culpability.[6]

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A now sizeable body of work shows that there is a connection between preschoolers' abilities to demonstrate theory-of-mind understanding and the development of executive-functioning skills typically associated with the *frontal cortex*. Executive-functioning skills are the processes and abilities that allow us to act in thoughtful, planned ways to achieve our goals. They include the ability to develop goals, plan the steps necessary to achieve those goals, and inhibit urges to do things that do not align with what we are aiming to do. Children's understanding of false-beliefs is most strongly predicted by response conflict executive functioning (RC-EF) – the ability to withhold urges in favour of rule-based behaviours, as is required, for example in the game "Simon Says."

Subject

While research clearly supports a relation between preschool children's RC-EF and their false-belief task performance, there is debate among researchers and theorists regarding why this relationship exists. The goal of this review is to summarize research on the nature of the relationship between RC-EF and false-belief understanding, and discuss implications for understanding social-cognitive deficits.

Research Context

Relations between false-belief task performance and RC-EF skills have been identified in children of different cultures[7] and socioeconomic status,[8] as well as within atypical populations.[9] Moreover, the correlation appears to exist independent of a range of relevant variables, including age, language abilities and general intelligence.[10] An early hypothesis was that the association might exist because standard tasks used to assess false-belief understanding have non-trivial RC-EF demands.[10] For instance, correctly predicting where someone with a false belief will look for something requires participants to do something unusual – say where something is not. This unusual response is particularly challenging given our habitual tendency to say where something is truly, and it is RC-EF that allows us to negotiate this challenge. Research in support of this view has shown that experimentally manipulating the RC-EF demands of false-belief tasks has predictable effects on children's performance -- as the demands go up, performance on these tasks declines.[11,12,13,14,15]

Though false-belief tasks likely do have non-trivial RC-EF demands like the one just described, it now seems unlikely that these demands provide a complete account of the association between

RC-EF and false belief. Instead, recent research suggests that there is a deeper relationship between RC-EF skills and false-belief understanding. Researchers have taken different approaches to examining the possibility that the association is a more intrinsic one. For instance, some have focused on the role played by common factors that may be pacing *cortical* maturation in the systems that are important for both theory of mind and RC-EF (e.g., *dopamine*).[16] Others have suggested ways in which RC-EF and theory of mind tasks might require similar kinds of cognitive abilities.[17] Another particularly interesting possibility is that RC-EF skills enable children to learn from the types of everyday experiences that provide them with information about other people's minds.

Research Results

There are several pieces of evidence that the RC-EF demands inherent to false-belief tasks cannot fully explain the relation between RC-EF and false-belief performance:

- RC-EF skills correlate not only with performance on standard false-belief tasks that involve children responding in ways that are unusual given their typical habits, but also with performance on tasks that do not require such responding. For instance, RC-EF is associated with the ability to accurately explain the false-belief-driven actions of a story character after he is shown to search unsuccessfully for an object.[18] Doing so does not obviously run counter to any established behavioural routine. These findings suggest that the relation between RC-EF and false-belief performance goes beyond superficial RC-EF task demands.
- Cross-cultural work shows that attaining a particular level of RC-EF skills does not alone translate to successful performance on false-belief tasks.[7,19] For example, Sabbagh and colleagues showed that Chinese and U.S. preschoolers performed similarly on false-belief measures, but the Chinese children were notably advanced in their RC-EF task performance relative to their age-matched U.S. counterparts; Chinese 3.5-year-olds performed similarly to U.S. 4.0-year-olds on the RC-EF tasks.[7] These findings suggest that RC-EF abilities alone are not sufficient to promote performance on measures of false-belief understanding – otherwise, the Chinese preschoolers would have demonstrated advantages on the false-belief measures as well.

Evidence that RC-EF skills are necessary for acquiring relevant theory-of-mind concepts comes from the following work:

- In the cross-cultural study described above, the relative levels of RC-EF skills in the Chinese and U.S. samples differed. Nevertheless, the relation between RC-EF and false-belief task performance was significant within both the U.S. and Chinese groups, and the magnitudes of the relations were similar. These findings suggest that RC-EF skills may be necessary, although not sufficient, for false belief understanding.
- Longitudinal work shows that early RC-EF skills predict later false-belief abilities, while the reverse relation—between early false belief and later RC-EF—is not significant.[20,21,22] Although a fully-controlled analysis has yet to be conducted, this relation holds true when a number of relevant variables are controlled, including age, verbal ability, and initial false-belief knowledge. Studies have found this general pattern of results when testing preschool-aged children across periods ranging from 5 months to a year.[20,21,22] These findings suggest that RC-EF skills contribute to the transitions in false-belief understanding that are taking place over this time.

Future directions

Assuming that RC-EF skills are important for children's developing understanding of mind, a next step is to characterize how exactly RC-EF skills might have this facilitative effect. Many researchers have argued that RC-EF abilities equip children with the tools necessary to learn about other minds from their experiences (see Benson & Sabbagh[23] for a review). Inherent to this theory is that relevant experience is also critical for theory-of-mind development. Indeed, a wealth of research shows that theory-of-mind is related to experiential factors, including parental use of mental state terms,[24] number of siblings in the home,[25] parenting style,[26] attachment[27] and socio-economic status.[28]

There are at least two mechanisms through which RC-EF might facilitate the process of learning about other minds from experience. First, having developed RC-EF skills might make children more likely to elicit and maintain naturalistic social interactions that provide a source of information about other minds.[21,22,29] Second, once children are engaged in an interaction, RC-EF skills might enable them to make use of the available false-belief-relevant information. Executive functioning may contribute to learning from experience by enabling children to 1) identify and attend to relevant variables,[29,30] 2) notice discrepancies between previously-established expectations and subsequent outcomes (i.e., expectation mismatches),[31] and, more speculatively, 3) flexibly update prior knowledge based on new information. Future research is necessary to

better understand the role that RC-EF plays both in supporting social interactions and in learning from socially-relevant feedback.

Conclusions

Research suggests that RC-EF skills are important for the development of a core aspect of social cognition – theory of mind – during the preschool years. Though more research needs to be done, we believe that RC-EF skills help children in the process of learning about other minds. More specifically, RC-EF skills help children to capitalize on the types of experiences that are important for developing their social-cognitive knowledge. Further work is necessary to clarify the more fine-grained mechanisms through which RC-EF skills exert their effect on this developmental process.

Implications for Parents, Services and Policy

Understanding others' mental states is critical for everyday communication and coordinated social interaction. With this in mind, an important question concerns how to best promote the development of these understandings among children who appear to have difficulties in understanding other minds. It might seem natural, for instance, for a parent or a daycare provider to encourage a child who has taken anothers' toy to "think about how that made her feel" in an effort to bolster the child's sensitivity to others' mental states. Research on the association between RC-EF and theory of mind, however, suggests that these natural interventions may have limited success unless children have the RC-EF skills necessary to make use of that information. Accordingly, supporting the development of young preschoolers' RC-EF skills might provide an important foundation for building knowledge about others' internal mental states. Fortunately, RC-EF skills have been shown to improve across a number of training experiences.[29] Our sense is that as these improve, so too will children's receptivity to information about others' mental states.

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Socioeconomic Status and the Development of Executive Function

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Introduction

Emerging research points to a relationship between childhood socioeconomic status and executive function performance. As both socioeconomic status and executive function are strongly and independently correlated with academic and health outcomes, an understanding of their interrelationship may have the potential to inform interventions designed to reduce disparities and promote healthy development for all children.

Subject

Socioeconomic status, a measure of social standing that typically includes income, education and occupation, has been linked to a wide array of life outcomes, ranging from cognitive ability and academic achievement to physical and mental health.[1-5] Understanding the pathways by which childhood socioeconomic status influences life outcomes is a question of critical importance to education and public health, particularly as global economic trends force more families into poverty.[6]

Current knowledge of socioeconomic status and child development indicates that children from higher-socioeconomic status families display better executive function – the ability to actively direct, control and regulate thoughts and behaviour – than children from low-socioeconomic status families. As executive function has been shown to predict school achievement[7,8] and is also associated with mental health outcomes,[9-13] it is possible that it may partially mediate the well-established link between socioeconomic status and academic achievement.

Problems

Research on this topic faces certain methodological challenges, resulting in part from the broad and sometimes ambiguous nature of the terms “executive function” and “socioeconomic status.”

"Executive function" refers to the higher-order processes such as inhibitory control, working memory, and attentional flexibility that govern goal-directed behaviour. This wide range of abilities can be operationalized by many different valid tasks, such as computerized cognitive tasks or parental reports of children's behaviour.[14] Likewise, "socioeconomic status" is a broad construct that may be measured in various ways.[15] Furthermore, it cannot be experimentally manipulated, making it difficult to disentangle genetic and environmental effects, as well as the individual contributions of the various conditions of poverty (e.g., increased family stress, reduced cognitive stimulation, worse nutrition, crowding and poor environmental conditions).[16,17] The difficulty of establishing causality in the relationship between socioeconomic status and executive function points to the need for large, well-designed, cautiously interpreted studies.

Research Context

Most studies of socioeconomic status and executive function have examined behavioural performance on developmentally appropriate executive function tasks, although a few recent studies[18-20] have, instead, used electrophysiological measure *prefrontal cortical* function. Executive function development has been investigated using both cross-sectional studies and large-scale longitudinal studies, such as the NICHD (National Institute of Child Health and Human Development) Study of Early Childcare and the Family Life Project. Many mediation studies use home-visit measures, such as the HOME inventory[21] or observations of parent-child interactions during free or structured play.[22]

Key Research Questions

1. What is the relationship between childhood socioeconomic status and executive function development?

2. What environmental factors mediate the relationship between socioeconomic status and executive function?

Recent Research Results

What is the relationship between socioeconomic status and executive function performance?

Research indicates that socioeconomic status influences neurocognitive systems unevenly. In a recent set of studies,[23-25] kindergarteners, first graders, and middle schoolers of varying socioeconomic status took batteries of tasks assessing independent cognitive systems, including

executive function, memory, language, and visuospatial cognition. Language abilities and executive function – particularly the domains of working memory and cognitive control – were among the most strongly affected.

Socioeconomic status disparities in executive function have been documented across a large age range, from infancy[26] through late childhood.[27] Studies have consistently found that higher socioeconomic status is associated with better executive function performance across different measures of socioeconomic status (such as family income-to-needs ratio or maternal education) and across different measures of executive function (such as working memory and inhibitory control).[28-32]

Executive function is supported by a region of the brain called the prefrontal cortex, which undergoes a long period of post-natal development,[33] and thus may be particularly susceptible to influences of childhood experience. Researchers have used event-related potentials (ERPs), which measure brain activity via electrodes placed on the scalp, to examine socioeconomic differences in neural processing in the prefrontal cortex. Two ERP studies[18,20] compared neural measures of selective attention across socioeconomic groups. In both cases, there were no differences on task performance, but neural processing evidence indicated that children from low-socioeconomic status attended more to irrelevant stimuli than did their high-socioeconomic status counterparts.

What factors mediate the relationship between socioeconomic status and executive functions?

Many environmental factors – such as stress, cognitive stimulation in the home, prenatal environment and nutrition – have been shown to vary along socioeconomic lines.[16,17] Any of these factors could contribute to socioeconomic disparities in executive function. Recent research has attempted to isolate environmental factors that mediate the socioeconomic status-executive function relationship. These mediating factors may inform interventions targeting socioeconomic status disparities in executive function and other cognitive and behavioural outcomes.

Several studies have found evidence that different aspects of the early family environment influence the development of executive function. For example, the quality of parent-child interactions, particularly during infancy, has been found to mediate socioeconomic status effects on executive function at 36 months of age.[22] Additionally, infants' stress levels (measured by salivary *cortisol*) partially explained the effect of positive parenting on executive function, suggesting that parenting may affect it by shaping children's stress responses.[28] Other studies

indicate that parent support of child autonomy,[34] parent scaffolding by non-intrusive help and guidance and family chaos[35,36] are important predictors of early childhood executive function.

Research Gaps

- The trajectory of executive function disparities is largely unknown. Socioeconomic status effects could grow over time, for example if they compound throughout development. Conversely, they could remain constant, or they could diminish, for example if counteracted by formal education.
- Research to date suggests that executive function development may be particularly susceptible to environmental influences in the years between infancy and preschool, but the exact timing and nature of this possible sensitive period awaits further research.
- It is difficult to disentangle the role that genetic and environmental factors play in the development of executive function, and the causal nature of the relationship between socioeconomic status and executive function has not yet been fully established. One way to establish causality in this relationship is to study outcomes of interventions that change factors of the childhood environment.
- While executive function differences are hypothesized to at least partly account for disparities in academic achievement, the extent to which interventions improving executive function will lead to improvements in other life outcomes merits further investigation.

Conclusions

Evidence points to a clear association between childhood socioeconomic status and executive function performance. This association appears to be mediated by aspects of the family environment, particularly factors involving the quality of the parent-child relationship and its ability to buffer stress. Research in this area is in its early stages, and studies currently underway will further our understanding of the nature of the socioeconomic status-executive function relationship and the environmental factors that contribute to it.

It is important to note that the existence of socioeconomic status-related differences in executive function and brain function does not in any way imply that these differences are innate or unchangeable. The brain is a highly plastic organ; in fact, an emerging body of research demonstrates that the neural correlates of cognition can be changed by environmental

experience.[37] We hope that elucidating socioeconomic status effects on cognitive development will allow interventions to target more specific cognitive processes and environmental factors, ultimately helping to reduce socioeconomic disparities.

Implications

Social policies designed to reduce socioeconomic status disparities have traditionally targeted either socioeconomic status itself or broad achievement outcomes. Research discussed in this article reveals additional targets: factors that mediate the relationship between socioeconomic status and executive function (e.g., the home environment), and executive function itself.

An emerging body of research[38] indicates that interventions can improve executive function in children. Successful interventions include training software, games, yoga and meditation, sports participation and specialized classroom curricula; lower-income children are among those who show the largest improvements.

In what ways can policies and services address the root causes of the socioeconomic status-executive function gap? Because the home environment has lasting effects on development, policies that address children's broader environments – rather than those that focus solely on school and child care settings – may be helpful. In particular, mediation studies point to the need for programs and interventions that reduce parental stress and increase children's access to cognitively stimulating activities and resources.[39]

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Executive Functions in the Classroom

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Introduction

Executive functions refer to cognitive abilities involved in the control and coordination of information in the service of goal-directed actions.[1,2] As such, executive functions can be defined as a supervisory system that is important for planning, reasoning ability and the integration of thought and action.[3] At a more fine-grained level, however, executive functions, as studied in the cognitive development literature, has come to refer to specific interrelated information processing abilities that enable the resolution of conflicting information; namely, working memory, defined as the holding in mind and updating of information while performing some operation on it; inhibitory control, defined as the inhibition of prepotent or automatized responding when engaged in task completion; and mental flexibility, defined as the ability to shift attentional or cognitive set among distinct but related dimensions or aspects of a given task.[4,5,6,7]

Subject

Executive functions are of growing interest in the field of child development research as an indicator of child health and well-being generally and of self-regulation specifically. The extent to which young children can appropriately resolve conflicting information and inhibit automatic responding when needed is seen as an indicator of the capacity for reflection and the ability to guide behaviour using future-oriented thinking. Such abilities should, in turn, lead to well regulated behaviour and to increased adaptation to a variety of contexts. Over the past two decades, a number of studies have demonstrated the feasibility of measuring executive function in young children.[8,9,10] As well, during this time period a number of studies have demonstrated that executive functioning is meaningfully related to a number of aspects of child development including social-emotional competence[11,12] and early academic ability.[13,14,15] Studies of the development of attention deficit hyperactivity disorder (ADHD) and conduct problems, as well as research on learning disabilities,[16] indicate that executive function deficits may be a central aspect of these disorders.[17]

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Problems

Several issues are relevant to research on executive functions in children. Primarily these issues relate to construct definition and validity and to the need for measures suitable for longitudinal use. Importantly, prior research with diverse test batteries with adult samples has indicated the presence of three distinct but interrelated factors for executive functions, namely, working memory, inhibitory control and attentional flexibility.[18] Similar measurement work with young children, however, it has yielded evidence of only a single underlying factor associated with executive function ability.[19,20] These findings have given rise to questions about a possible differentiation of executive functions from a single factor into distinct factors in adolescence or young adulthood. They have also led to questions about inherent limits on the measurement of executive function abilities in young children and the idea that assessments may become more precise with age. Additionally, these questions have highlighted the need for measures of executive function that can be used longitudinally with children. Most measures of executive function appropriate for use with young children tend to discriminate ability within a relatively narrow age range with ceiling and floor effects at older and younger ages.[21] Recently, however, a number of measures have been developed that are appropriate for longitudinal use.[22,23]

Key Research Questions

Given evidence indicating that executive function is important for school readiness and a central aspect of self-regulation in children, key questions relate to the identification of the relevant influences on the development of executive function and on its malleability. Of specific interest are questions relating to the ways in which poverty affects executive function development and the idea that effects of poverty on it might account in part for socioeconomic status (SES) related gaps in school readiness and early school achievement.

Recent Research Results

Recent research results provide valuable insight into the development of executive functions in early childhood. Several measures appropriate for longitudinal use with children as young as 30 months of age have been developed and are being validated. These include a version of the Dimensional Change Card Sort (DCCS) task appropriate for longitudinal use,[24] as well as a measure known as the Shape School.[25] Similarly, an innovative task battery has been developed that contains distinct tasks designed to measure working memory, inhibitory control and

attentional flexibility.

Increased precision in the definition and measurement of executive functions in children has gone hand in hand with longitudinal studies examining its development and its relation to multiple aspects of child development. Several studies, using a variety of measures, have demonstrated moderate to large associations between executive function ability and school achievement in the early elementary grades.[13,14,15,26,27] Importantly, these associations were observed when controlling for general intelligence or for early indicators of achievement, or both; in fact, executive function measures substantially attenuated or fully accounted for variance in outcomes associated with measures of general intelligence and early academic ability.

Results from a number of studies, including a population-based longitudinal sample of children followed from birth in predominantly low-income homes indicate that the quality of parenting mediates effects of the social and demographic risk on the development of executive functions at age 3.[28,29,30] As well, findings from the longitudinal study demonstrate that stress physiology, as indicated by levels of the *glucocorticoid hormone cortisol* in children, is related to executive functions and mediates in part effects of parenting and early risk on executive functions.[29]

Demonstration of relations between early experience and executive functions and between executive functions and social-emotional and academic outcomes have given rise to intervention studies examining executive functions as a potential target of efforts to promote social-emotional and academic competence in children at high risk for school failure. Results from these studies are generally positive, either suggesting or indicating that program-related changes in executive functions mediate, to some extent, program effects on academic and behavioural outcomes.[30,31,32]

Research Gaps

Current gaps in the literature include the need for greater precision in the longitudinal measurement of executive functions in early childhood, the identification of early precursors of executive function development that can be measured in the infant and toddler period, and evidence on the malleability or trainability of executive function development. Increased precision in the longitudinal measurement of executive functions will allow for a better understanding of the typical developmental course of executive function ability and on determinants of change in executive functions. Identification of early precursors can help to

provide information on early indicators which can be used to identify risk for executive function and self-regulation difficulties in early childhood. Innovative parenting or early child care programs might reasonably be expected to increase executive functioning in early childhood. A central gap in research on executive function development concerns the extent to which it is modifiable by experience.

Conclusions

Research on executive functions in early childhood has increased exponentially over the last decade. In general, the research literature on the construct indicates that executive functions can be reliably and validly measured in early childhood and that measures of executive function ability are meaningfully related to multiple aspects of child development including social-emotional and academic outcomes. As such, extant research has tended to confirm that executive function development is a central indicator of school readiness abilities. As well, research suggests that early executive function deficits may be sensitive indicators of risk for learning disability and perhaps of risk for early developing psychopathology. More research is needed, however, on the developmental course of executive function abilities, not only in early childhood but throughout middle childhood and adolescence. As well, research is needed to address relevant aspects of children's home and school environments that may promote or impede executive function development. Increased understanding of experiential influences on executive function development can be paired with a growing research base on the underlying neurobiology of executive cognition.

Implications for Parents, Services and Policy

Evidence indicates the relevance of executive function abilities to a number of aspects of healthy child development. This evidence highlights an ongoing need for the identification of specific aspects of experience and specific pedagogical approaches that exercise executive function abilities. Evidence linking executive function abilities to school readiness and early school achievement suggest the possibility of developing new curricular approaches or modifying existing approaches in early childhood programs and in the early elementary grades to more explicitly focus on executive function abilities. Current evidence suggests that early childhood programs that focus on self-regulation may be effective in promoting executive function abilities in children.[32,33] Indeed, it may be that diverse types of activities ranging from yoga to mindfulness training to martial arts to aerobic exercise have broad benefits on core attention shifting,

impulse control and working memory abilities that comprise executive functions.

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Reflections on the Development of Executive Function: Commentary on Knapp and Morton, Munakata et al., Rueda and Paz-Alonso, Benson and Sabbagh, Hook et al., and Blair

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Introduction

Children's executive function (EF) is now recognized to be a key aspect of human development. Interest in the development of EF has increased dramatically during the past decade, in part because individual differences in EF measured in childhood have been found to predict a wide range of developmental outcomes, including school readiness, social functioning, academic achievement, and even mental and physical health.[1] Indeed, impairments in EF are prominent features of numerous disorders with childhood onset, including ADHD, autism and conduct disorder. At the same time, however, research on EF has yielded evidence of considerable plasticity or malleability, and EF is emerging as a primary target of interventions designed to promote healthy development. The articles included in this section[2-7] provide a brief survey of major themes in current research on EF, identify questions for future research, and reveal clearly why the study of EF and its development is of enormous importance both for a basic scientific understanding of human behaviour and for more direct efforts to improve the lives of children.

Research and Conclusions

The following five questions are central among the many issues raised in this set of articles.

1. How do we measure EF in childhood and across the lifespan?

Blair[2] highlights the need for "measures suitable for longitudinal research," and Knapp and Morton[3] note that "tasks that are appropriate for testing EF at one age will not typically be suitable for testing EF in older children." Munakata et al.[6] also make this point. Having measures

that can be used across a wide age range is important if we want to compare EF across ability levels, whether age-related or not. Such measures also inform and are informed by our understanding of the structure of EF.

A major methodological advance in this area is the introduction of the new Cognition Battery from the National Institutes of Health (NIH) Toolbox for the Assessment of Neurological and Behavioral Function,[8,9] which includes measures of all three key aspects of EF: cognitive flexibility, inhibitory control and working memory. These measures include, respectively, a version of the Dimensional Change Card Sort,[10] a version of the Eriksen flanker task derived from the Attention Network Task,[11] and a List Sorting task derived from the Spanish and English Neuropsychological Assessment Scales.[12] The NIH Toolbox measures of EF are brief (less than five minutes each) and are suitable for use in repeated trials (with minimal *practice effects* for participants across the lifespan. Results from a validation study of the NIH Toolbox (N = 476) not only confirmed that the measures are reliable and valid but also yielded unique information about the structure of EF at different ages (from 3 to 85 years).[13] In general, there was good evidence of the increasing differentiation of EF from other aspects of cognitive function, which also showed increasing specialization, consistent with a characterization of neurocognitive development as interactive functional specialization.[14]

One thing the NIH Toolbox currently lacks, however, is a measure of hot EF. As Rueda and Paz-Alonso[4] note, there is an important distinction to be made between the more cool cognitive forms of EF that are prominent in cool contexts and the more hot, emotional forms of EF that play a key role in motivationally significant situations.[15] The former rely more heavily on networks involving lateral regions of *prefrontal cortex* (PFC; e.g., rostrolateral PFC) whereas the latter rely more heavily on networks involving ventral and medial regions of prefrontal cortex (e.g., orbitofrontal cortex, which is involved in the flexible re-appraisal of the affective or motivational significance of stimuli).

2. What have we learned about EF from studying the brain?

The use of the same measure of EF across the lifespan suggests that it develops most rapidly during the preschool years, but accelerates during the transition to adolescence.[9] Both periods appear to be marked by relatively rapid changes not only in behaviour but also in the structure and function of the EF-related PFC networks discussed by Knapp and Morton.[3] Although more research is required, these periods may be so-called sensitive periods of heightened sensitivity to

environmental influences, including both expectable (normative) influences and those that are more unique to individuals.[16]

In general, neurocognitive development can be seen as a dynamic process of adaptation wherein neural systems are constructed (by the child) in a use-dependent fashion. Fibres connecting regions within a network (and between networks) are myelinated in a use-dependent fashion, and unused synapses are pruned. Naturally, these processes are accompanied by corresponding changes in neurocognitive function. For example, in addition to improving EF performance, training EF in early childhood produces changes in brain electrical activity measured on the scalp (i.e., the amplitude of the *N2 component*), which reflects activation of the *anterior cingulate cortex* and is reliably elicited by detection of conflict.[17,18]

This example also illustrates another important characteristic of EF: there is a dynamic interaction between top-down EF processes and bottom-up influences on EF in particular and on behaviour in general. Relatively rapid, automatic and bottom-up neurocognitive responses (e.g., the N2-indexed ACC response to conflict) appear to influence relatively slow, voluntary and top-down EF processes (e.g., by triggering the PFC activation underlying reflection[19]), and this EF, in turn, appears reciprocally to influence the more bottom-up influences (e.g., reduction in N2 amplitude). Blair's longitudinal research on EF and stress/stress reactivity[20] addresses another aspect of this dynamic interaction.

3. What are the naturally occurring influences on EF and its development, and how do they work?

While it is clear that there are genetic correlates of EF, and also that are many environmental correlates of EF,some of which are most likely causal influences, it is, as Hook, Lawson and Farah[5] point out, "difficult to disentangle the role that genetic and environmental factors play in the development of executive function." Indeed, it may be impossible because these influences interact dynamically (over time) to yield EF phenotypes. To study this interaction, one needs to look at the bidirectional causal pathways linking genes, behaviour and aspects of the environment. For example, it will be of considerable interest to examine epigenetic changes accompanying naturally-occurring and experimentally-induced changes in EF.

4. What are the socio-demographic correlates of EF?

Both Blair[2] and Hook et al.[5] describe some of the many socio-demographic correlates of EF, which include socioeconomic status – and all the sources of variation that are captured simultaneously by this construct – but also, more precisely, specific aspects of parenting, social functioning and school achievement.

It is interesting to note that those aspects of cognitive function that are most strongly related to socioeconomic status, language and executive function, are precisely those that might be expected to be most dependent on enculturation.

Hook et al.[5] point out that research to date suggests that children from low socioeconomic status (SES) may be most likely to benefit from EF interventions. To the extent that the EF interventions provide specific opportunities that low-SES children are more likely to lack in their everyday lives (e.g., playing games that require inhibitory control, such as Simon Says), these children will be getting something that they may in fact need for the healthy or optimal development of EF to occur. Children in middle-class environments may be more likely to encounter these EF-skill-building (and playful, fun, motivating, etc.) exercises in their daily interactions with their parents, teachers, older siblings and others. Of course, they may also be more likely to encounter a safe and consistent environment, to be engaged in self-reflective, *psychologically-distanc-ing* discussions, to receive sensitive scaffolding from parents and others, and many other things that are likely to influence EF development.

It is also possible, however, that children who already have a strong foundation in EF, and are appropriately developmentally reflective and self aware, will be the children who can make the most out of any (necessarily limited) intervention. In any event, it will be important, as Blair[2] notes, to know something about the limits of EF plasticity. It would also help to know to what extent plasticity itself changes with age (e.g., in the form of sensitive periods), what variables influence plasticity, whether these influences change with age, and many other important questions. We currently know little more than that there is plasticity and that there appear to be periods of relatively rapid growth during which environmental influences play an important active role.

5. What do we know about the characteristics of interventions that improve EF?

The range of effective interventions that improve EF was comprehensively reviewed by Diamond and Lee.[21] Based in part on that review, I would suggest that effective interventions appear to

have the following characteristics:

a. They tend to require goal-directed problem solving in motivationally significant contexts. The exact role of motivation in these interventions is still unclear, but learning, and likely, degree of plasticity, is generally enhanced when children are interested in something (a goal, for example), and it's possible that there is an optimal range within which levels of interest, and motivation more generally, are most beneficial.

b. They typically require sustained self-reflective focused attention (i.e., sustained reflective reprocessing of information) on some challenge. To meet these challenges, children are called upon to slow down, reflect on the current context including relevant rules and plans, and select the appropriate rule or plan to implement.

c. They tend to involve adaptive challenges. Of course, challenges need to be adaptive in order for them to remain challenging, and for there to be something to be learned. In addition, however, degree of challenge surely interacts with motivation, and one consequence of continually challenging children is to help ensure that their motivation remains at an appropriate level.

d. They tend to involve a lot of repetition and practice. The importance of practice for skill acquisition in general is widely known, and it is now possible to observe the Hebbian processes whereby repeated practice of particular behaviours strengthens the neural pathways that underlie those behaviours.[22]

Conclusion

During the past decade, there has been considerable progress towards a more complete understanding of EF and its development during childhood. The articles[2-7] in this section provide an excellent introduction both to what has been learned so far, and to what remains to be revealed.

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Protective Role of Executive Function Skills in High-Risk Environments

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Introduction

Recently, the field of resilience has begun to focus on the protective role of executive functions in the school success of children facing adversity. Executive function, also termed cognitive control, describes goal-directed abilities to control thought, behaviour and emotions.[1] These skills can be seen in the ability to retain information in working memory, sustain or shift attention, inhibit automatic responses to perform an instructed or goal-directed action, and delay gratification.

EF skills develop rapidly in the preschool period[2] and are thought to provide a foundation for cognitive and behavioural school readiness.[3] In the classroom, executive function skills may manifest as the ability to pay attention, follow instructions, wait one's turn, and remember rules. These skills have shown particular importance for children exposed to early life stress, with recent research suggesting that executive function skills predict resilient school and peer functioning above and beyond intelligence level.[4,5,6,7]

Although these skills are protective for high-risk children, the development of executive function skills is vulnerable to exposure to trauma and chronic stress.[8] Children from various adverse backgrounds (e.g., homeless/highly mobile, poverty, early institutionalism, maltreatment, etc.) tend to have deficits in executive function.[6,7,9,10,11] Taken together, these findings suggest a need to lower chronic stress exposure and target building executive function skills through intervention and prevention efforts with children.

Subject

High-risk youth with more developed executive function skills show better cognitive and behavioural school readiness and performance.[3,12] These skills appear to enable children to navigate their constantly changing environment,[9,13] which may be especially key for children

developing in chaotic environments.

However, recent research has shown that children exposed to high levels of adversity may be less prepared to succeed in school, in part due to deficits in executive function skills.[6,7,9,10,11] These deficits may undermine children's abilities to succeed in academics and develop positive peer and teacher relationships.[12,14,15] This may have long-term implications for school success given that the achievement gap tends to persist and even widen throughout the school years.[16,17]

Given evidence that executive function skills are malleable to intervention and children who demonstrate poorer initial performance make greater gains,[18] recent efforts to improve high-risk children's transition to school have targeted building executive function skills prior to kindergarten.[4,19] Furthermore, research suggests that executive function skills are responsive to intervention across the school years.[18]

Problems

Studying the protective role of executive function presents several challenges. First, there are few measures capable of fully capturing executive function abilities for children who are experiencing delays in the development of these skills. Since exposure to chronic early life stress has been linked with impaired executive function skills in some children,[8] it is critical to be able to measure a wide range in functioning to fully capture the variability in these skills.

Current interventions to improve executive function skills employ a variety of methods including training, classroom curriculum, or physical activity.[18] Though these programs suggest executive function skills are malleable, they also show varied success in skill improvements.[20,21,22,23,24] Programs that utilize computer-based training show promise in enhancing executive function skills; however, improvements are specific to the domain trained (e.g., working memory) and do not seem to expand to other areas of executive function more generally.[18]

Other programs designed to boost executive function skills integrate executive function activities into the daily lives of children, such as the preschool curriculum Tools of the Mind.[25] Throughout this curriculum, children are encouraged to utilize private speech or visual reminders (e.g., a picture of an ear to remind them that they need to listen or pay attention) to develop inhibitory control skills. Initial findings suggested children in these classrooms develop better executive function skills.[26] However, recent studies have failed to replicate these findings,[27] suggesting possible challenges with the curriculum or fidelity of implementation.

Key Research Questions

Developmental studies designed to understand the protective role of executive function often address the following questions:

1. What is the mechanism through which executive function prepares children for school success?
2. What helps foster executive function skills in young children experiencing delays?
3. What helps protect these skills from chronic stress?

Recent Research Results

Research consistently indicates that children with more developed executive function skills prior to kindergarten experience greater school success.[6,7] For academic achievement, these skills may scaffold language and mathematic success.[12] In fact, in a low-income sample of children, researchers have found that executive function skills prior to kindergarten predict growth in both numeracy and literacy skills across the kindergarten year.[12] A successful transition to school may be particularly critical for children who have faced high levels of adversity and may be at risk for poorer school performance.

In addition to providing a cognitive foundation for learning, executive function skills may also support academic success by promoting appropriate classroom behaviour.[3] Many kindergarten teachers report that it is more important for children to control themselves in the classroom, follow directions, and not be disruptive than it is to know the alphabet or how to count to 20.[3] This suggests that teachers may find children with better executive function skills to be more teachable than children who are more distracted and prone to disruption.[3]

Furthermore, executive function skills may promote the development of positive teacher and peer relationships.[28] Studies suggest that there is overlap between the development of executive function and Theory of Mind (ToM), which is the ability to identify that others' desires and knowledge differ from one's own. These skills are associated with lower levels of aggression, better problem solving skills, and positive social skills.[29,30] Additionally, the ability to delay gratification may be linked with children's ability to regulate frustration and stress.[31,32]

Research Gaps

Currently, there is limited research on the effectiveness of interventions to boost executive function skills with very high-risk children. When developing interventions for these children, it may be critical to consider that children from a variety of adverse backgrounds may consistently demonstrate impairments in executive function.[6,7,9,10,11] Nevertheless, it will be important to remember that intervention needs and responses of children with different experiences may differ. For children currently experiencing chronic stress (e.g., homeless/highly mobile), it is unclear whether it is feasible to target executive function skills without first reducing stress and building coping skills. Future research will be needed to learn how best to tailor interventions to account for the needs of different children.

Conclusions

Studies consistently suggest that exposure to trauma or chronic early life stress may impair the development of executive function skills.[6,7,9,10,11] These skills appear to provide the foundation for school readiness through cognition and behaviour.[3,12] Children with better executive function skills may be more teachable.[3] Indeed, in a high-risk sample, children with better executive function skills at the beginning of kindergarten showed greater gains in literacy and numeracy than children with poorer initial skills.[12] Considering there is evidence that the achievement gap persists and may even widen across the school years,[16,17] it is critical that high-risk children begin school with as successful of a start as possible.

For this reason, there has been increased attention to interventions that promote executive function. Although there is evidence that executive function is malleable,[18,33] few interventions have attempted to boost skills in children currently experiencing toxic levels of stress. Efforts to design interventions that promote executive function in these children may need to address current levels of stress exposure and simultaneously work to reduce these to gain maximum benefit.

Implications for Parents, Services and Policy

Research to date underscores the importance of executive function skills for school success, especially for children living in high-risk environments. Programs designed to boost executive function have shown success across multiple levels, including school curriculum, computer-based training, and even physical activities, like martial arts.[18,33,34] Similar to computer-based training, parents may be able to promote these skills with games that require turn-taking, attention skills,

and memory. Furthermore, sensitive caregiving may promote these skills by shielding children from some of the chaos they are experiencing.[35]

Executive function skills also have been successfully targeted through school-based curriculum in preschool[26] and Head Start classrooms.[4,34] Experimental evidence suggests early childhood classrooms, like Head Start, can successfully build executive function skills by providing more self-regulatory support in a classroom (e.g., implementing clear rules and routines, redirecting or rewarding children's behaviour).[34] Increasing attention to executive function skills in early childhood programs may reduce the achievement gap that is apparent before school begins and persists throughout the school years.

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