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Educating Executive Function

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Abstract

Executive functions are thinking skills that assist with reasoning, planning, problem solving, and managing one's life. The brain areas that underlie these skills are interconnected with and influenced by activity in many different brain areas, some of which are associated with emotion and stress. One consequence of the stress-specific connections is that executive functions, which help us to organize our thinking, tend to be disrupted when stimulation is too high and we are stressed out, or too low when we are bored and lethargic. Given their central role in reasoning and also in managing stress and emotion, scientists have conducted studies, primarily with adults, to determine whether executive functions can be improved by training. By and large, results have shown that they can be, in part through computer-based videogame-like activities. Evidence of wider, more general benefits from such computer-based training, however, is mixed. Accordingly, scientists have reasoned that training will have wider benefits if it is implemented early, with very young children as the neural circuitry of executive functions is developing, and that it will be most effective if embedded in children's everyday activities. Evidence produced by this research, however, is also mixed. In sum, much remains to be learned about executive function training. Without question, however, continued research on this important topic will yield valuable information about cognitive development.

Keywords

Executive function; working memory; early childhood education; cognitive development

INTRODUCTION

The term executive function encompasses cognitive abilities that enable us to hold information in mind in working memory, to inhibit highly automatic responses to stimulation, and to shift the focus of attention between related but distinct aspects of a given task or problem. Executive, or cognitive control abilities, allow us to inhibit ingrained behaviors, to focus attention strategically, and to organize our thoughts in the face of distraction, complexity, and stress. Like many aspects of cognitive ability, executive

FURTHER READING

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Fuster, J. M. (2008). The prefrontal cortex. 4th Edition. Burlington MA: Academic Press.

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functions are useful in many different situations. Unfortunately, however, they also degrade rapidly under stress and pressure. If only we should all be so lucky to be as cool, calm, and collected as James Bond as he decides which wires to clip to defuse a nuclear bomb threatening to destroy civilization as its timer rapidly counts down to zero. If we could hang on to our thinking skills in the face of complexity and stress, in the face of pressure at work and in relationships, seemingly the world would be a better place and our lives would be more fulfilling (or at least we wouldn't get blown to bits). More realistically, we might inhibit impulses that get us into trouble, that lead us down rocky paths and into bad decisions that bring problems, sickness, and even death. On the more positive side, we might do better in school and in work, routinely avoid bad situations and encounters, and feel generally good about the choices we make. Of course, there are situations in life in which it is far better to respond quickly without thinking about things, such as when hitting the brakes when the car in front of us stops suddenly in traffic. It is also possible to 'over think' or ruminate on a given situation or topic in ways that can impair our wellbeing and our ability to take action. For most aspects of daily life, however, executive functions are more help than hindrance.

Fortunately, like many aspects of cognitive ability, executive functions tend to get better the more we practice them. The big questions are how much better and what kind of practice? Although seemingly the stuff of fiction, the possibility that we can develop executive function skills through training is a tantalizing and scientifically realistic possibility; but how can we do this in a way that will lead to some lasting and broadly applicable benefits? The answer is complex and, for the most part, currently unknown. There are, however, some good indicators of what an answer might look like and the types of benefits this might bring to ourselves and our society.

NEUROSCIENCE

To begin, it is useful to consider some basic neurobiology. The brain areas associated with the thinking skills that make up executive functions – working memory, inhibitory control, flexible shifting of attention – are primarily 'located' in what is known as prefrontal cortex (PFC). The neural circuits that support these skills, however, involve numerous brain regions, including areas of cingulate cortex and parietal cortex as well as subcortical structures, primarily the basal ganglia, amygdala, and hippocampus. In brief, specific networks of brain areas are active when we engage executive functions. These ares work together in an interconnected network to solve complex problems and help us reason about things. Most importantly for present purposes, some of the brain areas that are interconnected with PFC and make up the neural networks that support executive functions are part of the brain's limbic system; particularly the amygdala. The limbic brain registers the emotional and motivational significance of things—events, persons, places, tasks, etc. Relatively rapid and automatic signaling from the limbic brain to the PFC helps to direct our attention and thinking skills to things that are meaningful to us and away from things that have less meaning. In a word, the interconnected limbic-to-PFC circuitry (or corticolimbic connectivity if you want to impress your friends) underlies goal-directed purposeful actions, from rare actions (as in, defuse the bomb before it blows up) to daily activities (plan your

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day, solve a crossword puzzle, stop yourself from absent mindedly crossing the street against the light).

The interconnected limbic-to-PFC circuitry functions as a feedback loop. As the PFC receives input from the limbic brain, it feeds back on the limbic brain to modulate its input. In fact, the system is thought to work over short time periods to maintain a moderate level of input. That is, signaling from the limbic brain to the higher brain is in the form of neurotransmitters—dopamine, norepinephrine, the glucocorticoid hormone cortisol— that stimulate or more precisely modulate neural activity in the PFC brain areas that underlie executive functions[1]. When the increase in neurotransmitters/modulators is in a moderate range, PFC neural activity is strong and executive functions are working well. When the increase is too great, indicating that the person is under stress or over stimulated, or too low, indicating boredom and lethargy, then activity in PFC, and consequently the valuable thinking skills that this activity supports, is reduced.

BRAIN DEVELOPMENT AND EXECUTIVE FUNCTION SKILLS TRAINING

Given the general principle of brain function and development, namely that “cells that fire together, wire together” (the idea that much of the brain’s circuitry and strength of connectivity is shaped over time by experience; what is referred to as use-dependent activity), it is reasonable to expect that an individual might strengthen his or her executive function skills by strengthening the neural circuitry that underlies these skills. By repeatedly practicing executive function types of tasks, one would repeatedly activate the PFC-to-limbic brain neural circuitry (as well as PFC connectivity throughout the brain related to the task at hand). Presumably such repeated practice, as long as it did not become too boring and repetitive and remained moderately challenging, would strengthen the top down control from PFC to limbic brain, as well as other brain areas, leading to better control of emotional responses to situations and to a cooler, calmer, more collected self. Such a scenario is plausible and some evidence suggests that this might be the case. Individuals practicing a specific type of executive function skill, namely, working memory, over 6-8 weeks about 45mins per day get better at holding information in working memory and demonstrate changes in brain activity and even brain structure in relevant brain areas consistent with the increase in performance[2]. Primarily these activities are videogame-like activities that include things like remembering a series of locations, altering one’s actions in response to specific contextual cues, and overriding automatic responses. There is now a good body of evidence that repeated practice of executive skills (attention skills also) can be enhanced by practice in specific types of videogames and related types of activities[3-5].

An important question, however, is whether the improvements in these skills will translate into gains that generalize across a variety of situations and behaviors. This generalizability question is a complicated one and looms large in this area of research. The question is whether training merely leads the individual to become better on the trained task and on similar types of tasks, something known as near transfer. The alternative is far transfer, where training leads to more widespread benefits, that is, gains that matter in the real world like becoming better at controlling one’s emotions or getting better at some higher-level skill such as math. Evidence pertaining to this key question is mixed. Some studies indicate that

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training improves the control of behavior and attention for children with ADHD[6]. Some evidence also exists for other disorders (see Morrison & Chein[5]). Other studies, however, suggest that at best, near transfer is most frequently seen. One particularly interesting study with young adults demonstrated that working memory training led to improvements on a specific type of intelligence test that requires reasoning about matrices[7]. The idea here was that if intelligence and reasoning improved with training then perhaps many other things with which intelligence and reasoning are associated would also improve. Although the authors of that study did not look at broader underlying mental abilities beyond matrix reasoning, other similar studies with younger children have and demonstrate some benefits to broader abilities such as reading comprehension and mathematics that would be associated with general reasoning ability[8, 9]. Findings are far from definitive, however, and much remains to be done in this important area of research[10]. Methodologically speaking, there are many ways in which current studies could be improved. Some of these improvements are relatively straightforward, such as increasing sample size, while others are more complex, such as developing experimental manipulations to control for alternative, competing explanations for effects, such as social interaction[11, 12].

EXPANDING THE PLAYING FIELD

Given pressing issues of generalizability, two overarching principles of psychological development would seem to readily come into play. One is the “earlier is better” principle and the other is the ecological validity principle. The earlier is better principle suggests that efforts at training and building executive function skills will be most effective when PFC and other brain areas, including limbic brain areas, are developing rapidly in childhood as executive functions are first emerging. Given that neural networks are less specialized and differentiated in infancy and early childhood, the idea is that they will be more amenable to the effects of training. The second, and related, principle, ecological validity, suggests that in addition to starting early, incorporating the training exercises into things that we want kids to become better at, such as learning things in school, should be most effective. This principle reflects the common sense idea that if we want training to help people in their everyday lives, then training should take place in the contexts in which individuals are typically situated, such as school and work. Realistically, what good is such training if it only improves performance on specific executive function assessments?

With respect to the earlier is better principle, there is some evidence to suggest that earlier actually is better. Starting as young as infancy, some enterprising researchers have shown that training attention skills through structured computerized presentations of information can support the development of attention and provide a foundation for later executive functions[13, 14]. There are longitudinal data indicating that attention in infancy is a great predictor of later mental ability[15, 16], so training attention early to improve executive function makes good sense. As with the findings of training effects on the measure of intelligence in young adults, however, it may be that any observed positive effects would only be on superficial aspects of a given executive function task rather than broader underlying mental abilities. Longitudinal data are needed to determine whether starting early in life to train executive function skills through computer-based training of attention might lead to meaningful longer-term gains.

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Related to the second principle, the ecological validity principle, why not start training early but do it in the context of preschool and kindergarten? Given that executive function skills support reasoning and problem solving, they are very useful in the classroom. Executive function training would assist students in learning new information in a context that would likely lead to high generalizability (or at least be very useful). But how to do this? Despite its appeal, playing videogames for part of the day in the classroom, on its own disconnected from other activities, would not seem to be a good idea (sorry kids.) Some insightful curriculum specialists, however, have been way ahead of the curve in this regard. Several years ago, these specialists recognized the power of structured play to encourage the development of complex thinking skills in young children. This is thought to occur primarily through the ability of structured play to encourage children to plan ahead and to reflect on their behavior, in a word, to be self-directed and, hence, self-regulated. Many experts consider the development of self-regulation skills, of which executive functions are the crown jewel, to be the most important objective of high quality preschool — to help children focus attention, be emotionally expressive, not be impulsive, and to engage in purposeful and meaningful interactions with caregivers and other children.

The use of child-directed, structured play and classroom activities are characteristic of Montessori education and of a program known as Tools of the Mind. Tools of the Mind and Montessori are thought to promote executive functions by providing children with opportunities for self-direction in choosing and completing learning activities. The programs are also thought to promote executive function skills by having children work collaboratively in ways that require each child to take the perspective of his or her partner. In addition, Tools of the Mind uses structured play and most importantly the planning of play in advance to encourage reflection and thereby the development of executive function skills.

Evaluations of Tools of the Mind and Montessori and similar educational approaches have been generally favorable, suggesting that they do indeed help young children build their executive function skills and to learn more quickly. For example, a ‘randomized’ (lottery system) evaluation of Montessori education indicated benefits to children’s executive functions as well as to academic achievement and play behavior[17]. Similarly, a recent randomized controlled trial evaluation of the Tools of the Mind program with children in kindergarten demonstrated benefits to executive functions and academic abilities as well as the ability to control attention in the face of emotionally arousing images[18]. These results followed RCT evaluations of the program with preschoolers, one of which found benefits to executive function skills[19] with some evidence of academic benefits (Barnett et al., 2008) while another found no effects of Tools of the Mind on any aspect of child ability[20]. A third evaluation of the preschool program is now underway and is showing effects of the program on executive functions and academic abilities. In theory, by fostering the development of self-regulation, high quality preschool and early elementary education is understood to assist children in making sense of and building on the academic types of information that they will increasingly be exposed to throughout their school careers. Too much of an academic focus in early education without sufficient support for a strong foundation in self-regulation is ultimately self-defeating and likely to lead to worse, not better, school outcomes for children.

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In addition to structured play, another approach to fostering executive functions is mindfulness meditation. Although not specific to school, this approach can and often is practiced by school children. Research on mindfulness meditation in adults indicates that mediation for even a short time improves attention and executive functions[21]. Educators and researchers are developing interesting techniques for assisting young children in meditating with some promising findings suggesting that the techniques are working[22]. Some of the best evidence for the effects of mindfulness meditation on executive functions comes from research with young adults. That research has shown not only effects on behavioral measures of executive functions but also on brain activity and connectivity in the limbic brain to higher brain PFC circuitry[23]. These effects suggest that although earlier may be better, it is perhaps never too late (or at least better late than never.) Research findings suggesting effects of training on executive functions in adults hold the very interesting possibility that we all might improve our well being and our job performance, interpersonal relationships, and so on through executive function training of one type or another, be it mindfulness meditation or videogame playing, or something else entirely. Perhaps recognition of the potential for change and the power to control one's thinking skills – that effort matters more than ability – is enough to lead people to give it a try. It's certainly something worth thinking about.

CONCLUSION

A number of studies with children and adults have shown that executive function skills -- particularly working memory — can be improved. The idea that we can increase our executive function abilities in ways that matter in our daily lives is less well established but would seem to be a realistic possibility. There have been very rapid advances in a relatively short period of time in the scientific understanding of executive functions and of how the brain works in general. It would seem likely that issues related to near and far transfer of executive function training will be resolved in the not too distant future and that executive function training will begin to make its way into a variety of activities, including educational and vocational training. An important aspect of progress in this research and its application, however, will be to pay close attention to how and under what circumstances training is actually effective and resulting in lasting gains. It is perhaps very easy to sell the idea that playing some sort of videogame, just like taking some sort of pill, might actually make one smarter and improve one's life. If history and prior scientific evidence are any guide, however, genuine increases in ability are only likely to come through sustained and ongoing practice and persistence in things that matter to us most.

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