

# Hot and Cool Executive Function: Foundations for Learning and Healthy Development

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## ABSTRACT

Executive function (EF) refers to the set of core self-regulatory skills required for deliberate, goal-directed problem solving. These skills, which are exercised when children pause and reflect before reacting, provide a foundation for learning in a classroom context. They make it possible to pay attention, think flexibly, keep information in mind, and resist distractions. A distinction between two types of EF, hot (more emotional) and cool (less emotional), emerges early in development and helps explain why self-regulation can be especially difficult in the face of meaningful consequences. Both hot and cool EF improve with practice, and working with young children on both types of EF skills is likely to be beneficial for school readiness and beyond.

*Jenny is a bright 3-year-old sitting quietly at a small table with a graduate student, Jim, who asks her to help him solve a problem: Jim can either get one candy to eat now, or, if he waits until they are done playing games, he'll get four candies to eat later. Jenny prudently says Jim should wait and get more candy to eat later. When Jenny herself is given the same choice, however, she stares at the candy, imagining how delicious it will be, and suddenly notices that she's hungry. She chooses one candy now.*

In both cases—deciding for oneself or deciding for someone else—children draw on their developing executive function (EF) skills to the extent that they stop and reflect on the problem before responding. EF skills are the cognitive skills essential for deliberate, goal-directed problem solving, and they include: (a) cognitive flexibility (thinking flexibly about something, including seeing things from another point of view), (b) working memory (holding information in mind and working with it, as when rehearsing it), and (c) inhibitory control (stopping impulsive responses and resisting distraction). Together, these effortful processes provide a foundation for active learning and adaptation: They make it possible for children to sustain attention, keep information in mind, refrain from responding immediately, resist distraction, tolerate frustration, consider the consequences of different behaviors, and plan for the future (Carlson, Zelazo, & Faja, 2013).

Good EF is related to positive outcomes across the life span. In early childhood, EF skills are needed to learn in a classroom context (Marcovitch, Jacques, Boseovski, & Zelazo, 2008), and children with better EF skills tend to do better on measures of math and literacy, even in a comparison of children at the same level of IQ (Blair & Razza, 2007). Kindergarten teachers recognize this as well and report that being able to sit still, pay attention, and remember and follow rules are more important for success in their classes than is early literacy and numeracy (McClelland et al., 2007). It is relatively easy to teach traditional content (reading, writing, and arithmetic) to children who can control their behavior in the classroom—children who can pay attention and reflect on what they are learning. Indeed, there is evidence that children with better EF skills actually learn more from a given amount of instruction and practice (Benson, Sabbagh, Carlson, & Zelazo, 2013). They also show a larger gain in math achievement between kindergarten and first grade, especially on applied problems (Hassinger-Das, Jordan, Glutting, Irwin, & Dyson, 2014), suggesting that EF skills are important for learning new material as one moves through grades.

The link between EF and key indices of successful adaptation continues to be seen across the life span. Better EF in childhood (e.g., waiting for a larger reward) predicts higher SAT scores in high school, as well as better emotional coping (Mischel et al., 2011), and it predicts better health, more wealth, and reduced

criminal offenses in adulthood (Moffitt et al., 2011). In contrast, childhood difficulties with EF are a common feature of several clinical disorders (see box Clinical Implications).

## Hearts and Minds

In the example described earlier, Jenny showed good EF when choosing for Jim but not when choosing for herself—a common pattern for 3-year-olds, who are about 3 times more likely to choose the delay option for the experimenter than for themselves (Prencipe & Zelazo, 2005). Why does choosing for someone else make such a difference in children's behavior? Why does wanting something really badly sometimes seem to throw reasoning out the window?

To answer these questions, it is helpful first to distinguish between two different types of EF, hot and cool (Zelazo & Carlson, 2012). Hot EF is involved in situations that are highly motivating and emotional, where the stakes are high, as when Jenny was choosing for herself. In these contexts, hot EF skills make it possible to manage one's emotions and control one's tendencies to approach or avoid meaningful things. In contrast, cool EF is more prominent in situations that are not as emotional, as when Jenny was choosing for Jim. Hot and cool EFs are both forms of effortful, top-down, self-regulatory processing that depend on the prefrontal cortex, but they vary in the extent to which they require the management of emotion, including the modulation of basic motivations (e.g., to approach or avoid something).

### Clinical Implications

The development of executive function (EF) can be disrupted by many factors, including genetics and environmental stressors. Deficits in EF have been found to be related to many childhood disorders, such as attention deficit disorder, attention deficit-hyperactivity disorder (ADHD), autism spectrum disorder, conduct disorder, Tourette's syndrome, and obsessive-compulsive disorder. These disorders differ considerably from each other, but they all include deficits in EF skills such as controlling impulses, focusing attention, and anticipating consequences (Zelazo & Müller, 2002). These EF deficits can occur despite high levels of IQ, which can be frustrating for parents and teachers who know that they are dealing with bright children but don't know why the children aren't meeting expectations.

Many children get diagnosed with more than one of these disorders, as there are overlapping symptoms among disorders. Understanding the different types of EF may help professionals better understand the disorders in relation to one another. For example, one study found that ADHD is more associated with abnormalities in brain regions that are involved in cool EF, whereas conduct disorder is more associated with abnormalities in regions involved in hot EF (Rubia, 2011). In the future, it is possible that distinguishing between hot and cool EF deficits could help in diagnosing childhood disorders.



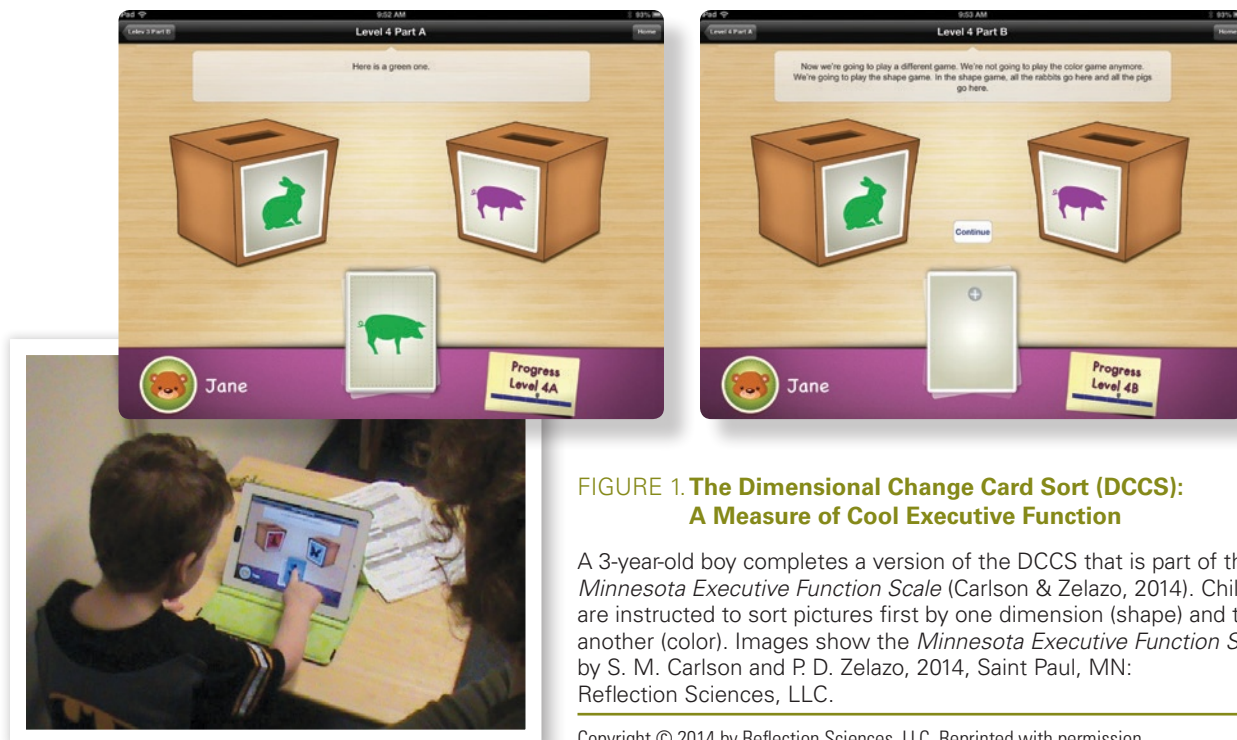
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Within the prefrontal cortex, hot and cool EFs depend primarily on different regions. Whereas cool EF relies mainly on the lateral prefrontal cortex, hot EF relies more on ventral and medial regions of the prefrontal cortex, including the orbitofrontal cortex, which is involved in flexible appraisals of motivational significance (Zelazo & Carlson, 2012). This has been demonstrated in lesion studies (where specific parts of the brain are damaged) and in studies using brain imaging technology, such as functional magnetic resonance imaging (Bechara, Damasio, Damasio, & Anderson, 1994; Manes et al., 2002).

Case studies of individuals (both children and adults) with lesions to the orbitofrontal cortex provide striking evidence that it is possible to do well on laboratory tasks such as card sorting yet still have enormous difficulty dealing with meaningful social and emotional situations in one's daily life.

A widely used measure of cool EF is the Dimensional Change Card Sort (DCCS; e.g., Zelazo, 2006). In one version, presented on a tablet computer, children are shown a display with two boxes, one with a green rabbit on it and one with a purple pig (Figure 1). They are then shown test cards with either green pigs or purple rabbits. Children are first instructed to sort by color: All the green ones go in one box, and all the purple ones go in the other. They are given five cards to sort in this way by dragging the virtual test cards across the touch screen. For 3-year-olds, this generally goes well. The hard part comes next. Children are then directed to stop sorting by color and now begin sorting by shape instead: All the rabbits go here, and all the pigs go here. Now, children need to reflect on the fact that there are two ways to sort the cards, stop sorting in the first way, keep the current rules in mind, and switch to sorting by those rules. Many preschoolers fail to keep up with these demands and instead continue to sort the cards by the first dimension, in this case, by color. Curiously, they do this despite knowing the current rules and telling them



**FIGURE 1. The Dimensional Change Card Sort (DCCS): A Measure of Cool Executive Function**

A 3-year-old boy completes a version of the DCCS that is part of the *Minnesota Executive Function Scale* (Carlson & Zelazo, 2014). Children are instructed to sort pictures first by one dimension (shape) and then by another (color). Images show the *Minnesota Executive Function Scale* by S. M. Carlson and P. D. Zelazo, 2014, Saint Paul, MN: Reflection Sciences, LLC.

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to the experimenter, and this gap between knowing and being able to act on that knowledge is a classic sign of difficulty with EF. The DCCS is a measure primarily of cool EF because, for most children, the rules are arbitrary and the stakes are low.

Measures of hot EF, on the other hand, look different. One example is the Gift Delay task (Kochanska, Murray, Jacques, Koenig, & Vandergeest, 1996). The directions are fairly simple: The experimenter tells children that they are going to receive a present but that, first, the experimenter needs to wrap up the gift so that it will be a surprise. The child is asked to sit facing away from the experimenter and refrain from peeking while it is being wrapped. The experimenter then noisily wraps up the gift. For many children, it quickly becomes very difficult not to peek over their shoulder or turn around to see what is going on behind them. Children have to keep in mind the rule, “Don’t turn around?” What makes the task particularly difficult for children, however, is the need to control their strong desire to approach the attractive gift. If this desire is not well regulated, it has the potential to undermine top-down EF skills, making it difficult to remember and heed the simple rule. Managing these emotions and inhibiting the strong desire to peek makes the task difficult for reasons that differ somewhat from the reasons why the DCCS is difficult.

Although hot and cool EFs can be dissociated, to some degree, in laboratory tasks and as a consequence of brain lesions, most real-life tasks involve demands on both: behaving appropriately at school, interacting with friends and siblings, learning new skills such as riding a bike, and so forth. A good example of this is “Red Light, Green Light,” a common children’s game in which the goal is to get to the finish line. Someone calls out, “Green light!” and all the children move as quickly as they can

toward the finish line, but when the caller says, “Red light!” they must stop moving immediately. If they move after “Red light!” is called, they are sent back to the beginning. This game involves cool demands: There is a rule to remember and follow (if the caller says “green light,” then I can move; if the caller says “red light,” then I have to stop), and it is necessary to pay close attention to what the caller says. However, being a competitive game, it is also rife with demands on hot EF: the desire to get to the finish line first (vs. the need to stop), the need to inhibit forward movement on short notice, and the dreaded consequence of getting sent back to the starting line. These demands make the game more difficult, as well as more exciting.

## Development of Hot and Cool EF

The human brain evolved to allow individuals to adapt to the environments they encounter. As a result, the brain develops, to a large extent, as a function of individual experience. When particular neural networks in the brain are activated and used, these networks become stronger. Unused connections between neurons are pruned away. One consequence of the way the brain develops is that it becomes increasingly differentiated with age, with particular regions becoming specialized for certain types of processing (Johnson, 2001). EF follows this principle. In a large study using the NIH Toolbox, Zelazo et al. (2013) found that two measures of cool EF (the DCCS and a flanker test of inhibitory control and selective attention) were more strongly correlated with vocabulary for younger children (3–6 years old) than for older children (8–15 years old), and a factor analysis of performance on a wide range of cognitive measures showed an increasing number of factors with age (Mungas et al., 2013).

Studies using a variety of measures of cool EF tend to find that performance on all measures corresponds to a single factor in young children (Allan & Lonigan, 2011; Sulik et al., 2010; Wiebe et al., 2011; Willoughby, Blair, Wirth, & Greenberg, 2010). In a study of older children and adolescents (7–21 years old), Huizinga, Dolan, and van der Molen (2006) found evidence for two factors, cognitive flexibility and working memory. In adults, measures of EF often correspond to three factors, cognitive flexibility, working memory, and inhibitory control, which separate out in statistical analyses (Miyake et al., 2000).

One distinction that emerges relatively early, however, is that between hot and cool EFs (Bernier, Carlson, & Whipple, 2010; Carlson, White, & Davis-Unger, 2014; Kim, Nordling, Yoon, Boldt, & Kochanska, 2013; Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011). For example, Carlson and colleagues have regularly found that children who do well on one type of EF task (“conflict” tasks) do not necessarily do well on another type (“delay” tasks). Conflict tasks include the DCCS and generally require cool EF. Delay tasks, on the other hand, are measures of hot EF. Examples include delay of gratification and the Gift Delay task. Researchers have also found that the two types of EF predict different outcomes. In preschoolers, hot EF is associated with inattentive–overactive problem behaviors, whereas cool EF is associated with academic outcomes (Kim et al., 2013; Willoughby et al., 2011).

The development of both hot and cool EFs is a protracted process that lasts from birth into adulthood. Although EF skills go through a dramatic “growth spurt” during the preschool years, especially between about 3 and 5 years old, improvements continue throughout adolescence and beyond. Hot and cool EFs seem to follow different developmental trajectories, however, with hot EF lagging behind and continuing to develop later. One study with children 8–15 years old found that, on cool tasks, there was a transition toward more adult-like performance at around 10 years old, but on hot tasks, such a transition did not occur until around 14 years old (Prencipe et al., 2011). This difference might be especially relevant for understanding teen behavior, because this is another age group in which the gap between knowing (e.g., not to drink and drive) and doing (e.g., an emotional context, such as peer pressure) looms large (e.g., Gardner & Steinberg, 2005).

## Practicing Executive Function

This distinction between hot and cool EFs can be useful for understanding young children’s behavior. Telling a preschool child to pick up the toys in his room, in the hallway, and in the living room before he can go out and play may seem like a simple direction. However, when this is viewed through the lens of hot and cool EF demands, we can see how this task may be perceived as overwhelming. For cool EF demands, the child has to remember the three locations, keep them in mind, and also monitor his progress. For hot EF demands, there is the desire to play with the toys instead of putting them away, as well as

the desire to go outside and play, which could make it difficult to focus on the task at hand. Reducing the EF demands placed on young children can scaffold their developing EF skills and allow them to practice their skills successfully. This can be as simple as giving one direction at a time or removing desirable distractions from the immediate vicinity so children won’t have to struggle to stay focused. Being aware of such demands in children’s environments could reduce behaviors that may seem like defiance or laziness but may really be symptoms of the protracted development of EF.

Hot and cool EFs are not fixed traits that children are simply born with, but rather skills that can be improved by training and practicing. Research shows that a number of activities can improve children’s EF skills, including computer training, games, aerobics, martial arts, yoga, mindfulness, and completing school curricula. Interventions that have been shown to improve EF tend to require children to reflect before responding; they generally involve repeated practice; and they get progressively more challenging as children improve. For example, in a study by Espinet, Anderson, and Zelazo (2013), children who failed the DCCS were given a new DCCS (with different shapes and colors) and taught to pause before responding, reflect on the hierarchical nature of the task, and formulate higher order rules for responding flexibly: “In the color game, if it’s a red rabbit, then it goes here; but in the shape game, that same red rabbit goes there.” Compared with children who received only minimal yes–no feedback (without practice in reflection) or mere practice with no feedback at all, children who received reflection training showed significant improvements in performance on a subsequent administration of the DCCS. Improvements were also seen on other tasks, including measures of perspective taking or theory of mind, and these behavioral changes were accompanied by changes in children’s brain activity measured using electroencephalography (which records electrical activity on the scalp that is due to the firing of neurons in the cortex). This research has suggested that it is possible to train high-level skills such as reflection and cognitive flexibility, with corresponding neural changes that may reflect myelination, changes in synapses (connections among neurons), and synaptic pruning (reduction of connections among neurons that are not used). A consequence is that trained networks become more efficient, so reflection and EF occur more automatically and more quickly, providing more time for thoughtful reflection before overt action or decision making.

There has been less research on interventions to improve hot EF, but there is evidence that mindfulness and related contemplative practices lead to improved emotion regulation skills in both adults and children (Broderick, 2013; Ortner, Kilner, & Zelazo, 2007; Zelazo & Lyons, 2012). EF is impaired by factors such as stress, loneliness, and lack of physical fitness, suggesting that working with children in a holistic manner, focusing on emotional and social development as well as specifically on EF, may be the best way to improve EF-related outcomes (Diamond & Lee, 2011).

There are many simple activities that parents and teachers can do to help children work on hot and cool EFs (see box Practice Executive Function (EF) With Young Children). Improvements in both hot and cool EFs could help prepare children to learn more efficiently and effectively in the classroom and promote positive outcomes throughout the life span (Marcovitch et al., 2008). If children arrive at school with well-practiced EF skills, they may be more likely to feel confident, learn easily, and get along with the teachers and with other students; they may also be less likely to be called out for behavior problems.

## Conclusion

Knowing about hot and cool EFs helps to make sense of Jenny's behavior in the opening story. Why does choosing for someone else make such a difference in children's behavior? In this case, when Jenny was choosing for Jim, the EF demands were relatively low. Cool EF skills were needed to weigh the alternatives, but these demands were manageable for Jenny. She was able to think about the best way to get the most candies and recommend that strategy

### Practice Executive Function (EF) With Young Children

Here are a few simple ways to help children to exercise their developing executive function (EF) skills.

- 1. Sing the BINGO song!** One way to sing this song is to take out a letter in each verse and substitute it with a clap. In the first verse, you sing **B-I-N-G-O**, then in the next verse, you sing **\*clap\* -I-N-G-O**, then **\*clap\*-\*clap\* -N-G-O**, and so forth. By substituting claps for letters, this song can help children practice EF skills such as remembering rules and inhibiting impulses.  
**Extra challenges:** Try stomping or just being silent instead of clapping. For older children, try taking out letters starting from the last letter instead of the first. There are lots of ways to change it up to get children's minds working harder!
- 2. Practice belly breathing.** One facet of mindfulness training is to focus on breathing. One way to teach children how to take deep, calming breaths is to have them lie on their backs and place a small stuffed animal on their stomachs. Then have them practice slowly, gently rocking the stuffed animal up and down by deeply breathing in and out. Then encourage the children to breathe like this when they are upset, and it can help calm them down. This provides practice in managing one's emotions and arousal, a key part of hot EF.
- 3. Encourage pretend play.** When children pretend, they have to inhibit reality and think about objects in multiple ways (e.g., this is actually a banana, but I could pretend it is a telephone). There is evidence that pretend play is related to both hot and cool EFs, with understanding pretend–reality distinctions related to cool EF and performing pretend actions related to hot EF (Carlson et al., 2014). Encouraging children to plan out the scenario they are going to play and what props they will use—and helping children to follow through on that plan—can also be forms of EF practice (Diamond, Barnett, Thomas, & Munro, 2007).

## Learn More

### Web Sites

#### About Kids Health

[www.aboutkidshealth.ca/En/News/Series/ExecutiveFunction/Pages/Executive-Function-Part-One-What-is-executive-function.aspx](http://www.aboutkidshealth.ca/En/News/Series/ExecutiveFunction/Pages/Executive-Function-Part-One-What-is-executive-function.aspx)

Executive Function is an online series of six short articles on EF by Philip David Zelazo that was prepared for parents and appears on The Hospital for Sick Children's Web site.

#### Executive Function

[http://deltraining.com/courses/Executive\\_Function/content-frame.htm](http://deltraining.com/courses/Executive_Function/content-frame.htm)

A Web site about EF created by the Washington State Department of Early Learning to provide professional development for individuals working with children.

### Videos

#### InBrief: Executive Function: Skills for Life and Learning

[www.youtube.com/watch?v=efCq\\_vHUMqs](http://www.youtube.com/watch?v=efCq_vHUMqs)

#### Key Concepts: Executive Function

[http://developingchild.harvard.edu/key\\_concepts/executive\\_function/](http://developingchild.harvard.edu/key_concepts/executive_function/)

Online videos about executive function produced by the Center on the Developing Child at Harvard University.

### Online Article

#### Executive Function Problem or Just a Lazy Kid: Part 1

Margolies, L. (2011)

<http://psychcentral.com/lib/executive-function-problem-or-just-a-lazy-kid-part-1/0009272>

to Jim. When choosing for herself, however, Jenny faced strong demands on her developing hot EF skills. To delay for herself, Jenny would have needed all the cool EF skills she showed while choosing for Jim, but in addition, she would have to inhibit the impulse to take the desired candy immediately. As is typical for 3-year-olds, this proved to be too big a challenge for Jenny, and she opted for immediate gratification. Thinking about behavior in terms of hot and cool EFs may help adults to better understand young children's behavior, and focusing on the development of these skills can help promote positive outcomes that extend across the life span.

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**Philip David Zelazo, PhD**, is currently the Nancy M. and John E. Lindahl Professor at the Institute of Child Development, University of Minnesota. He is editor of the two-volume *Oxford Handbook of Developmental Psychology* (2013), lead developer of the EF measures for the *NIH Toolbox*, and lead scientist (Cognitive Health Domain) for the National Children's Study of more than 100,000 individuals (and their parents) followed from birth through adulthood to examine a wide range of environmental and biological influences on healthy development. He obtained his bachelor's degree in psychology from McGill University and his doctorate in psychology from Yale University.

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