Under New Management

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From the libidinous characters that pervade cable TV to the sheer volume and variety of impulse-buy-ready goodies in the grocery store checkout aisle, today's cultural landscape seems to suggest that people fundamentally lack self-control and constantly are giving in to temptation. In reality, though, most adults are fairly skilled at managing their attention, emotions, and behavior. Adults' self-control skills are a far cry from those of children, who, as APS Past President Walter Mischel demonstrated with his renowned marshmallow tests, often can't hold out even a few minutes once the allure of a sweet treat enters the equation.

The apparent chasm between the executive functioning skills of children and adults has become a popular focus of psychological research, as scientists seek to understand the development of executive control in the brain and the implications that development has for future behavior and outcomes. Leaders in developmental and neurobiological psychological science gathered earlier this year for an Integrative Science Symposium at the inaugural International Convention of Psychological Science in Amsterdam, the Netherlands, to discuss the latest theories and evidence in this area.

The conception of executive control as primarily inhibitory is common — we must *stop* ourselves from eating that second brownie, or getting distracted while driving, or buying that new gadget that we can't afford — but it doesn't tell the whole story, as all of the speakers highlighted in their own ways. APS Fellow Yuko Munakata, of the University of Colorado, explained that executive functioning also requires proactive monitoring — an awareness of situational contexts that could require us to exercise inhibitory control.

"It's not simply about being able to stop yourself … there's a proactive monitoring process [that happens] before you even get to that point that aids in the ability to stop in those moments," she said. A person on a diet must not only stop himself from eating something unhealthy, but he also must avoid situations, like going grocery shopping on an empty stomach, that will make it difficult to resist temptation.

Munakata explained that a key part of child development is the shift from a primarily reactive form of control over one's behavior, in which a person exerts control in the moment, to a proactive form that requires planning ahead of time rather than on the fly. Munakata has found that young children, those paragons of poor self-control, generally show reactive executive functioning, which could explain why they just can't seem to stop themselves from blurting out the answer in class or grabbing the single marshmallow placed in front of them rather than waiting to receive two. Because younger children rely on the reactive form of self-control, they cannot use the proactive monitoring necessary for effective executive functioning.

Based on these findings, Munakata theorized that training older children — who are capable of engaging in the proactive form of self-control — in proactive "executive monitoring" could help facilitate the use of executive functioning. This hypothesis has now been supported by studies showing that proactive monitoring interventions successfully increased executive control.

Children often need to have their behavior directed by adults for their own safety (and their parents' sanity), but allowing them to determine their own goals and how to reach them is another critical component in the development of executive functioning, said Munakata. She has examined how the increasingly structured activities and social lives of children may affect the development of executive control and has discovered that children who spent more time participating in unstructured activities scored higher on a verbal fluency task (a measure of executive functioning) than did those who spent more time on structured, externally directed activities.

“The key finding from this project is that the way that children spend their time predicts their self-directed executive functioning,” she explained.

Executive functioning develops most rapidly during the preschool years and the transition to adolescence, according to APS Fellow Philip D. Zelazo, a professor at the Institute of Child Development at the University of Minnesota. The increased rate of development during the preschool years can be illustrated by the Dimensional Change Card Sort (DCCS), a classic rule-switching task in which subjects must sort a set of cards with two variable dimensions (e.g., two different colors and two different shapes) according to one rule (color), and then switch to sorting them by the other rule (shape). Three-year-olds struggle mightily at this task, tending to perseverate (to continue sorting according to the first rule); however, Zelazo found that most 4-year-olds can switch between two sorting rules relatively fluidly.

He attributes this difference to the ability of older children to engage a key component necessary for executive functioning: reflection. In the rule-switching paradigm, reflection allows children to see the larger context of two conflicting rules and to form a hierarchical system to resolve the conflict.

“Like adults, they seem to understand that they know two different ways of approaching these stimuli … they seem to stop, step back, and reflect on their own knowledge about these rules,” Zelazo explained. In other words, reflection enables a child to move beyond, “A goes here, and B goes there” to “If I am sorting by color, then A goes here, but if I am sorting by shape, A goes there.”

Research by Stacey D. Espinet, Jacob E. Anderson, and Zelazo has shown that interventions focused on increasing reflection can improve both performance on cognitive flexibility tasks and the overall development of executive function, and researchers are beginning to understand the actual neural mechanisms that underlie the process of reflection.

One of the brain regions Zelazo has homed in on is the anterior cingulate cortex (ACC), which connects to many of the prefrontal cortical structures involved in executive functioning. This area also is a locus of conflict detection, signaling when there are multiple rules that contradict each other — such as the “sort by color/sort by shape” conflict of the DCCS. Electrophysiology studies have revealed that the amplitude of a specific ERP (brain response) component called N2, which has been shown to correspond to conflict detection, is lower in subjects who show cognitive flexibility and perform well on tasks such as the DCCS than it is in other subjects.

“We interpreted that [as] the downregulation of this ACC-generated detection of the need for executive function — and reflection in particular — in those children who spontaneously detected the problem, engaged in reflection, and then, in effect, shut off that warning signal,” Zelazo explained.

This discovery has enabled him to study reflection training in terms of both behavioral outcomes (improved executive function) and the neural correlate that mediates those outcomes (lower N2 amplitude, which translates to improved efficiency in conflict detection). He has found that even a 15-minute reflection training session can significantly improve performance on the DCCS and significantly decrease N2 amplitude.

APS Fellow Eveline Crone (Leiden University) also has examined the ACC and its relation to executive function, but she focuses on a different metacognitive process called “performance monitoring,” which is the use of feedback to adjust for future performance. Electrophysiological and neuroimaging studies have revealed that brain responses to negative feedback tend to occur in the ACC, and informative performance feedback — that is, feedback valuable for adjusting future behavior, be it positive or negative — is mediated through the ACC and the frontoparietal network, a region known for its role in attentional control.

Crone and colleagues set out to explore how feedback monitoring develops using a longitudinal study examining neural and biological measures, behavior, and educational outcomes in subjects ages 8 to 28 over a 2-year period. One of the experiments involved a simple learning task during which participants were asked to sort pictures of animals into three boxes, learning the rules for which animal belonged in which box based on visual feedback from the computer (a plus sign for an animal in the correct box, a minus sign for incorrect placement).

When researchers matched task-performance data to fMRI data taken as the subjects were completing the task, they found that those who performed better tended to activate the frontoparietal network to a greater extent than those who performed poorly. When they controlled for performance in order to examine age-related patterns, they found evidence that older subjects, similar to high performers, recruit the frontoparietal network often when performing the task.

Crone and colleagues noted large variability in the data, but when they matched subjects’ performance to their individual brain activity, a strong correlation between the two emerged. When they combined these data with reading and mathematical fluency measures, they found that activity at the onset of the longitudinal study in a specific area of the frontoparietal network, the dorsolateral prefrontal cortex (DLPFC), reliably predicted reading and mathematical ability 2 years later on an individual level.

Crone then examined the connections between the DLPFC and other brain regions, including how changes in those connections might mediate the changes in the DLPFC itself. She found that, over time, the DLPFC lost connections with motor areas but developed increased connectivity with the caudate nucleus, an area associated with goal-directed action and movement. Indeed, increased connection between the DLPFC and the caudate nucleus was correlated with increased performance on the learning task.

“It seems that the protracted development of [the] prefrontal cortex may also result in increased flexibility,” Crone explained. “This increased flexibility may have advantages which are important in [adolescence], such as adaptation to different social contexts.”

APS Board Member Annette D. Karmiloff-Smith, a professor at the Centre for Brain and Cognitive Development at Birkbeck, University of London, United Kingdom, served as discussant for the symposium and expressed her appreciation for the wide variety of experimental tasks, overall methodologies, and age ranges represented in the three talks. She particularly highlighted the contribution of Walter Mischel for laying the foundations of developmental studies of executive function and encouraged the search for dynamic neural networks rather than static brain regions. She also suggested other avenues of research that could significantly contribute to current theories and models of the development of executive control, such as the following:

- studying executive functioning in infants to better understand development across the entire life span;
- studying the role of the environment and socioeconomic status;
- examining neurodevelopmental syndromes of known genetic origin, which almost always involve impaired executive functioning, to gain insight into possible genetic influences;
- investigating the role of sleep and sleep disruption;
- exploring nonverbal intervention strategies for improving executive control; and
- the need to go beyond group data to understand individual differences.

Karmiloff-Smith stressed the importance of approaching the study of executive function “not just from a cognitive point of view, for improving school outcomes and so forth, but also for effective motivational and emotional outcomes.” Finally, she raised the questions as to whether executive function training could be detrimental and impede the automatization of cognitive processes. She commended the researchers for their dynamic, multifaceted approaches that eschew simplification of the development process. “It’s going to be a very complicated story,” she said, “and my message has always been that we have to embrace complexity.”