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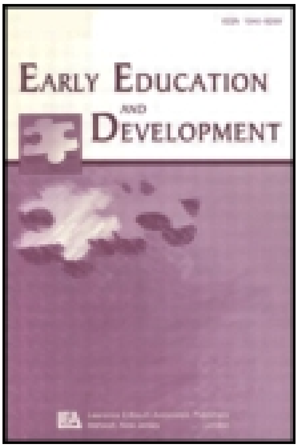

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Research Findings: Executive function begins to develop in infancy and involves an array of processes, such as attention, inhibition, working memory, and cognitive flexibility, which provide the means by which individuals control their own behavior, work toward goals, and manage complex cognitive processes. Thus, executive function plays a critical role in the development of academic skills such as reading. This article describes the development of executive function in young children, describes the brain structures and changes associated with that development, and then reviews recent research on the critical role of executive function in early reading development and education. *Practice or Policy:* Because executive function and its associated brain developments parallel reading acquisition, work in executive function has profound implications for fostering the successful development of reading skills, including prereading skills, word reading, and reading comprehension. Instruction that helps children learn to manage the multiple features of spoken and printed language will help ensure that children develop the reading-specific executive functions that will enable them to manage the complexities of reading processes throughout their lives.

Almost three decades ago, Royer (1983, p. 205) noted, ''Reading is the natural interface between developmental and educational psychology.'' Indeed, Royer was ahead of his time because in recent years the developmental sciences have blossomed, offering new ways to view children's learning with important implications for education in general (Siegler, 2000; Sternberg & Lyon, 2002; Twardosz, 2007) and for reading education in particular (Katzir & Paré-Blagoev, 2006). Education scholars have begun to look to the new frontier of cognitive neuroscience to enrich and inform their understanding of learning (Melzer, 2007) and reading processes (Cartwright, 2008). However, according to a recent report from the National Council for the Accreditation of Teacher Education, the curricula of teacher preparation programs have been hard-pressed to keep pace with the rapid advances in the developmental sciences (Leibbrand & Watson, 2010).

This special issue thus addresses a critical need by assisting early child educators in understanding and applying new research in neuroscience to educational practice. In this paper I describe an area of research in cognitive neuroscience that focuses on *executive function* (EF): ''a collection of inter-related processes responsible for purposeful, goal-directed behavior,'' such

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as ''anticipation, goal selection, planning, initiation of activity, self-regulation, mental flexibility, deployment of attention, and utilization of feedback'' (P. Anderson, 2002, p. 71). Clearly, these mental processes have particular relevance for the development of academic skills such as reading. However, until recently most research on EF focused on adults; individuals with prefrontal brain damage; or children with cognitive difficulties, such as those with attention-deficit/hyperactivity disorder or autism (Hughes, 2002; Zelazo & Müller, 2002). In the following sections I describe the development of EF in young children, the brain structures and changes associated with that development, and the important role of EF in early reading development and education.

EF: WHAT IS IT AND WHEN DOES IT DEVELOP?

To complete tasks and manage their own behavior, individuals must purposefully guide their mental processes and actions to meet particular goals. As noted previously, EF includes such processes as attention, planning, initiation of activity, inhibition, working memory, shifting of attention, and mental flexibility. These are important for everyday tasks, such as when a toddler restrains his or her impulse to touch a crystal vase on the coffee table, as well as academic tasks, such as writing this article.

As one might imagine, I did not spontaneously generate the words on this page. Rather, I read and reflected on a call for papers on neuroscience perspectives on early development and education, which prompted me to set a goal of writing a paper on the intersection of work in cognitive neuroscience and early reading education. To meet that goal I engaged in several deliberate tasks. For example, I planned my approach to the paper; engaged in search strategies to find resources to support my writing; focused my attention on sources relevant to my chosen topic while inhibiting my responses to unrelated, interesting articles and other distractions; reflected on the varied backgrounds of potential readers; organized information from the various sources into a coherent outline to support readers' understanding of my topic; managed flexibly and integrated ideas from various sources in a way that would provide readers with new information on the role of EF in early reading education; maintained ideas, words, and sentences in memory as I typed the text of the article; and reread my writing, which provided feedback that prompted revisions. The deliberate mental actions that were required for me to meet my goal—planning, strategic processing, focused attention, inhibition, reflecting on others' perspectives (metacognition), organization, cognitive flexibility, memory, and response to feedback—are all components of EF, and these develop from infancy into adulthood. Furthermore, just as these processes were essential to the completion of my writing task, they underlie many of the academic, social, and emotional developments of children.

The definitions and descriptions of EF that I have offered thus far include quite a long list of processes, which is consistent with research in this area. For example, similar to the definition offered by P. Anderson (2002) above, Hughes (2002, p. 69) described EF as ''a complex cognitive construct that encompasses the set of processes that underlie flexible goal-directed behaviour (e.g., planning, inhibitory control, attentional flexibility, working memory).'' Researchers vary in the number and array of skills they describe as components of EF, but each definition has at its core the notion of control, either conscious or unconscious, of one's own mental (and physical) actions (Dawson & Guare, 2010; Zelazo, 2004). See Table 1 for a list of processes typically included in the umbrella of EF and definitions for each.

TABLE 1
Processes Typically Included in the Umbrella of Executive Function (P. Anderson, 2002; V. A. Anderson et al., 2001; Dawson & Guare, 2010)

Process	*Definition*
Attentional control	The ability to focus on particular information or a particular task regardless of distractions or fatigue
Cognitive flexibility	The ability to consider multiple bits of information or ideas at one time and actively switch between them when engaging in a task
Inhibition	The ability to restrain one's normal or habitual responses (also called *response inhibition* or *inhibitory control*)
Initiation	The ability to overcome inertia and begin a task
Metacognition	The ability to take a step back and reflect on thoughts, perspectives, and mental processes and assess their effectiveness
Organization	The ability to impose order on information and objects or to create systems for managing information or objects
Planning	The ability to decide which tasks are necessary to complete a goal, including understanding which ones are most important and the order in which the tasks should be completed to most effectively reach the goal
Response to feedback	The ability to adjust one's behavior or alter one's plans in the face of new information
Self-regulation	The ability to control one's own behavior and emotions in order to achieve goals
Switching or shifting	The ability to change one's attentional focus from an initial idea to a new one (this is related to cognitive flexibility)
Working memory	The ability to hold information in mind to support the completion of tasks

So how does EF develop? As early as infancy, children begin to develop the ability to manage their own behavior to meet particular goals, such as when a baby learns to follow a caregiver's gaze and direct his or her attention toward a newly labeled object, which supports language learning (Carpenter, Nagell, & Tomasello, 1998). Recently, research on infants' brain activity while they engage in joint attention has provided evidence of memory and attention processes in infants as young as 4 months of age (Hoehl, Reid, Mooney, & Striano, 2008). Individuals continue to develop the mental skills necessary to manage behavior and thought processes into adulthood (Bjorklund, 2005; Dawson & Guare, 2010; De Luca et al., 2003), with accelerated periods of development occurring between 2 and 5 years of age and again at puberty when children's EF looks quite adult-like (V. A. Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Dawson & Guare, 2010; Zelazo & Müller, 2002). As one might expect, EF varies with socioeconomic status, with children of lower socioeconomic status having less well developed EF at kindergarten than their peers with higher socioeconomic status, even when parent involvement is controlled (Neuenschwander, Röthlisberger, Michel, & Roebers, 2009).

Although EF develops across the lifespan, many critical developments occur in the preschool years. As noted previously, even infants have the capacity for some EF, demonstrating attention and memory as early as 4 months of age (Carpenter et al., 1998). By age 3, children demonstrate working memory, attentional flexibility (the ability to shift attentional focus), and inhibitory control (Hughes, 1998), indicating that they can remember information to help them complete tasks, shift attention from one aspect of a task to another, and are capable of controlling their own behavior by restraining their own actions (although they don't always do it). Inhibitory control improves between ages 3 and 6 (Montgomery & Koeltzow, 2010), which helps children adjust to the behavioral and academic demands they encounter in school. Cognitive flexibility, a skill particularly important for reading (Cartwright, 2009), improves markedly between ages 4 and 5, with additional refinement between ages 7 and 9, reaching relative maturity by age 12 (Davidson, Amso, Anderson, & Diamond, 2006; Jacques & Zelazo, 2001; Smidts, Jacobs, & Anderson, 2004). Davidson and colleagues (2006) compared various aspects of EF across 4- to 13-year-olds and confirmed that working memory and inhibition develop earlier than cognitive flexibility, which, although fairly mature at age 13, is not yet at adult levels. I return to a discussion of cognitive flexibility when I discuss the role of EF in reading development.

HOW DOES BRAIN DEVELOPMENT RELATE TO EF?

Activity in the frontal and prefrontal cortex is associated with EF (Bunge & Wright, 2007; Dawson & Guare, 2010; Eslinger, Biddle, Pennington, & Page, 1999; Kane & Engle, 2002; Montgomery & Koeltzow, 2010; Zelazo & Müller, 2002). The cortex is the outer layer of the brain that we use for our highest brain functions, and it is divided into sections, or *lobes*. The occipital lobe of the cortex, for example, is located at the back of the brain (and thus the back of the head) and is associated with visual processing. The frontal lobes are located in the front of the brain, behind the forehead, and activity and growth in these areas underlies EF in children and adults.

The cortex is composed of *neurons,* or nerve cells. The production of most of our neurons is completed at about 7 months after conception, which means we generally are born with all of the neurons that we will have throughout our lives (Bjorklund, 2005; Johnson, 2011). Brain weight more than triples by age 5 and quadruples by adulthood (Bjorklund, 2005; Dawson & Guare, 2010). Clearly, much growth and development occur over that time period, with many important changes occurring by age 5. Throughout development, brain weight increases because neurons' dendrites increase in number and size, neurons' axons grow, and new *synapses* (the junctions at which neurons communicate with one another) are formed—a process called *synaptogenesis.* Thus, though new neurons are rarely added during brain development, the existing neurons change shape and size. In addition, throughout development a fatty sheath called *myelin* wraps around the axons of neurons to increase the efficiency of neural communication. Myelin works much like the insulation around an electrical cord because it ensures that neurons' electrical impulses are protected from interference, improving the speed of communication in the brain and nervous system, which results in improved mental processing (see Bjorklund, 2005; Dawson & Guare, 2010; and Johnson, 2011, for reviews of brain development).

These various brain components can be divided into gray matter, which consists of neurons' cell bodies and dendrites, and white matter, which consists of bunches of myelinated axons. Across childhood different areas of the brain are myelinated at different times, with brain regions associated with sensory systems myelinated before birth and the motor cortex (the brain regions that control movement) receiving myelin across the first year of life (Bjorklund, 2005; Sowell et al., 2004). The prefrontal and frontal cortex (the areas associated with EF) are myelinated across childhood and into adolescence, which correlates with the improvements in EF over that period (Dawson & Guare, 2010; Gotgay et al., 2004; Sowell et al., 2004). In addition to increases in myelin, brain growth is also attributable to an overproduction of new synapses in children's brains, which peaks between ages 4 and 5, around the same time that children's

EF shows a marked increase. Preschoolers have far more synapses than adults, and these connections provide the raw material for brain development. Experience (and the associated brain activity) determines which synapses are kept, and inactive synapses are removed via a process called *synaptic pruning* (Bjorklund, 2005; Dawson & Guare, 2010; Johnson, 2011), which underscores the important role of children's experiences in brain development.

With respect to development of the prefrontal and frontal cortex, the sites of EF, development begins in infancy and continues into adolescence (Johnson, 2011; also see Zelazo & Müller, 2002), which parallels the development of EF (see above). Within the frontal and prefrontal cortex, development proceeds from the back to the front, from the bottom to the top, and from the middle portions out to the sides (Gotgay et al., 2004; Montgomery & Koeltzow, 2010). As more and more neurons become myelinated, the amount of white matter in the frontal and prefrontal cortex increases. And from infancy to adolescence, as new synapses are created and unused synapses are pruned away, the amount of gray matter increases, plateaus, and then decreases. Myelination and synaptic pruning processes occur simultaneously in development; consequently, infants have more gray matter than white matter, whereas adolescents have more white matter than gray, which reflects the way experience shapes, or sculpts, the developing brain, refining the brain structures to more efficiently process information (Amso & Casey, 2006; Gotgay et al., 2004; Sowell et al., 2004). Finally, a second surge in synaptogenesis occurs around ages 11 to 12, when new synapses develop in the already-pruned frontal lobes (Dawson & Guare, 2010), adding strength to the newly refined brain structures to support the advances in EF seen at that time (V. A. Anderson et al., 2001; Dawson & Guare, 2010; Zelazo & Müller, 2002).

WHY IS EF IMPORTANT FOR DEVELOPING READING SKILL?

Reading is a complex mental process that requires the coordination of many elements, such as words' sounds, meanings, word parts (e.g., prefixes and suffixes), syntax (word order), and strategies that support reading comprehension (Adams, 1990; Pressley, 2006). Skilled readers must manage all of these features, coordinating them seamlessly for effective comprehension (Cartwright, 2009). Given that EF and associated brain regions develop across early childhood and into adolescence, the period of time when children are developing word-reading skills and reading comprehension, the research on EF has tremendous implications for children's success as readers.

Even before children begin to read, EF may affect the development of important prereading skills. For example, Farrar and Ashwell (2008) demonstrated that children's cognitive flexibility, assessed with theory-of-mind tasks, was related to their rhyming ability, which contributes to later reading skill. In addition, Blair and Razza (2007) found that preschoolers' inhibitory control, assessed with a peg-tapping task, was significantly related to essential prereading skills in kindergarten: phonemic awareness (or the awareness of individual sounds in spoken words) and letter knowledge. Consistent with this finding, children's effortful control—their ability to control their own behavior, which is indicative of EF—is positively related to word- and nonword-reading ability in early elementary school; however, surgency, which is related to impulsiveness, reduces that effect (Deater-Deckard, Mullineax, Petrill, & Thompson, 2009). In a productive series of longitudinal studies, Wagner, Torgesen, and colleagues have shown that

EF specific to the processing of phonological information plays an important role in developing word-reading skills (e.g., see Wagner, Torgesen, & Rashotte, 1994). Specifically, they have found that phonological awareness (the awareness of sounds in speech and the ability to manipulate those sounds), phonological memory (the ability to hold representations of sounds in mind), and rapid phonological naming (the ability to produce rapidly phonologically accurate names for objects and symbols) contribute to children's developing word- and nonword-reading skill across the elementary years (Wagner et al., 1997). In addition to these phonological-specific measures of EF, other general assessments of EF are related to children's word-reading skills. For example, van der Sluis, de Jong, and van der Leij (2007) found that shifting and updating, each assessed with composites of several tasks, were related to word-reading efficiency in 9- to 12-year-olds. Furthermore, Welsh, Nix, Blair, Bierman, and Nelson (2010) found that working memory, assessed with a backward word task, and attentional control, assessed with the Dimensional Change Card Sort, not only were related to preschoolers' print knowledge and phonological awareness but also predicted these children's reading skills at the end of kindergarten, including word reading, nonword reading, and memory for story content.

As Welsh and colleagues' (2010) work suggests, EF also plays an important role in the development of reading comprehension. Studies investigating the role of EF in comprehension typically compare good and poor comprehenders who have age-appropriate word-reading abilities, thus controlling for the effects of word reading on reading comprehension. For example, Sesma, Mahone, Levine, Eason, and Cutting (2009) found that 9- to 15-year-old poor comprehenders had significant deficits in planning and working memory, even when word-reading skill and vocabulary were controlled. In Sesma and colleagues' study, planning was assessed with the Tower of London task and working memory was assessed with the Freedom from Distraction Scale of the Wechsler Intelligence Scale for Children. In a similar study, Locascio, Mahone, Eason, and Cutting (2010) found that 10- to 14-year-old poor comprehenders had significant deficits in planning ability, assessed with the Wechsler Intelligence Scale for Children Elithorn Mazes task and the Dells-Kaplan Executive Function System Trail-Making and Mazes tests.

Inhibition is another EF with which poor comprehenders struggle. For example, De Beni and Palladino (2000) found that 8-year-old poor comprehenders with adequate word-reading ability were significantly less able than their better comprehending peers to inhibit irrelevant information on a working memory task that required them to remember the final words in a series of sentences. Cain (2006) explored these differences further and found that poor comprehenders did not differ from their counterparts with better comprehension on short-term memory tasks that involved recalling short lists of digits, concrete words, or abstract words. However, when these students were given more complex working memory tests that required them to supply final words in sentences and then remember those words later or to count arrays of dots and then remember the total numbers later, poor comprehenders performed significantly more poorly than their peers with better comprehension. Their mistakes indicated that the poor comprehenders were unable to inhibit irrelevant information on these complex recall tasks, suggesting that the inability to suppress irrelevant information might cause significant comprehension problems in these young readers.

Other research investigating the role of EF in reading proficiency has focused on special populations who might provide additional insight into the nature of reading processes. For example, Reiter, Tucha, and Lange (2004) studied EF in a group of children with dyslexia, a specific reading disability, and compared their processing to that of typical readers. They found that children with dyslexia had significantly lower working memory, assessed with backward digit span and visual tasks; inhibition, assessed with the Stroop color-naming task; planning, assessed with the Tower of London task; and cognitive flexibility, assessed with a switching task that required children to alternate button-pressing responses to visually presented letters and digits. Another special population of interest in studies on the influence of EF on reading processes is children with attention-deficit/hyperactivity disorder because children with attention deficits have specific impairments in EF. Recently, Hart and colleagues (2010) demonstrated shared genetic and environmental influences on reading and attention deficits in children with attention-deficit/hyperactivity disorder, suggesting that EF deficits are genetically linked to reading disability. Finally, in a recent training study, when 9- to 12-year-old children with attention difficulties received 20 to 25 days of EF training, their reading comprehension improved (Dahlin, 2011). The training involved daily completion of an individualized, computer-administered program of visual and verbal working memory items that increased in difficulty as children progressed through the program each day. At the end of the training period, children showed no improvements in word reading. However, trained children's working memory and reading comprehension improved significantly.

The research reviewed thus far has indicated that EF may influence reading development from preschool throughout the school years. In particular, prereading skills are related to inhibition and cognitive flexibility; word-reading proficiency is related to working memory, inhibition, shifting, updating, and attentional control; and reading comprehension is associated, at the very least, with planning, working memory, and inhibition. These findings are promising and point to the important role of EF in reading acquisition; however, most studies of the effects of EF on reading comprehension have not used reading-specific measures of EF, which leads to the question of how, more specifically, EF might contribute to children's developing reading comprehension skill.

My research has focused on the role of cognitive flexibility, another specific EF, in children's and adults' reading skill. As noted previously, skilled readers must coordinate flexibly multiple aspects of reading tasks for successful comprehension (Adams, 1990; Pressley, 2006). However, many struggling readers are inflexible, focusing only on words' letters and sounds without paying attention to meaning, which impairs their reading comprehension (see Cartwright, 2010, for a review). Thus, cognitive flexibility has particular relevance for developing reading comprehension. I wondered whether it was possible to measure flexible thinking about the components of words that many children find difficult to coordinate: sounds and meanings. Thus, I adapted a general assessment of cognitive flexibility, the multiple classification task (Bigler & Liben, 1992; Golbeck, 1983; Inhelder & Piaget, 1964), to measure the flexibility with which children (and adults) could process words' sounds and meanings simultaneously. The assessment requires that individuals sort four sets of 12 printed words by sound and meaning at the same time into a 2×2 matrix, which necessitates that individuals flexibly go between sound and meaning as they complete the 2×2 sorts. The assessment is administered individually and begins with a model sort to show the child how the 2×2 sort works. The teacher tells the child, ''I have some cards for you to sort, and you can sort these cards two ways at the same time, by how they sound and what they mean. Here, let me show you.'' After introducing the assessment, the teacher places each card into the 2×2 matrix, one card at a time, reading each word aloud as it is placed (Cartwright, 2002, 2007, 2010; Cartwright, Marshall, Dandy, & Isaac, 2010). See Figure 1 for a correct sort of one set of words on the sound–meaning cognitive flexibility assessment;

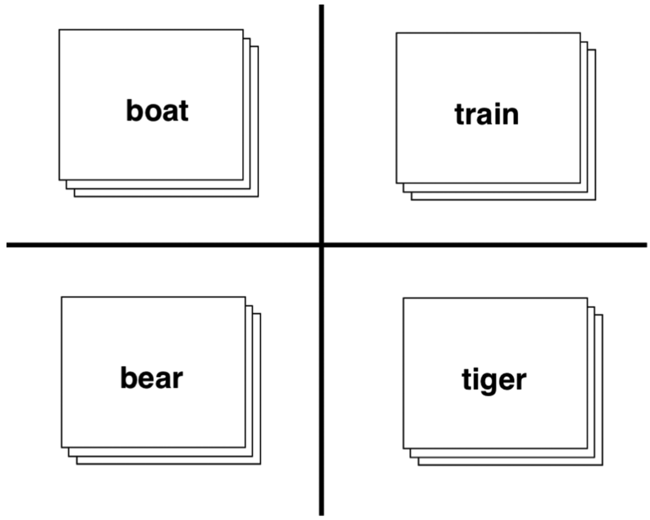

FIGURE 1 A correct sort on the sound–meaning cognitive flexibility assessment.

the words in this set are sorted by initial sound, /b/ and /t/, and by meaning, animals and vehicles. After the model sort, the child is asked to sort four new sets of 12 cards, one set at a time; each set is sorted by a different combination of sounds and word meanings. If the child sorts correctly, the teacher requests an explanation for the sort; if the child sorts incorrectly, the teacher corrects the sort and then requests an explanation from the child. Correct explanations must focus on the two sorting dimensions, sound and meaning, and sorts are scored on the accuracy of the sort and explanation as well as sorting time, following prior work (Bigler & Liben, 1992; Cartwright, 2002, 2007; Cartwright et al., 2010; Diamond & Kirkham, 2005; Golbeck, 1983).

Subsequent studies have found that sound–meaning cognitive flexibility, assessed with the task described above, contributes significantly to reading comprehension in first and second graders (Cartwright et al., 2010), second to fourth graders (Cartwright, 2002), and college students (Cartwright, 2007) and develops across the lifespan (Cartwright, Isaac, & Dandy, 2006). In each of these studies reading comprehension was assessed with the Passage Comprehension subtest of the Woodcock Reading Mastery Tests–Revised, Form G (Woodcock, 1987), which required individuals to supply missing words in prose passages. These findings were promising and led to studies of sound–meaning cognitive flexibility training, which resulted in improvements in sound–meaning cognitive flexibility and reading comprehension in second- to fourth-grade typical readers (Cartwright, 2002) and second- to fifth-grade struggling readers (Cartwright, Clause, & Schmidt, 2007). In both training studies reading comprehension was assessed at pretest and posttest with the researcher-administered Woodcock Reading Mastery Tests–Revised Form G and Form H, respectively. In addition, in the training study with struggling readers, a second assessment of reading comprehension, a school-administered comprehension assessment that required students to read passages and answer questions about those passages, also indicated significant improvements in reading comprehension for trained students.

Sound–meaning cognitive flexibility training differed from the assessment and was modeled after prior successful cognitive flexibility training (Bigler & Liben, 1992). Whereas the sound–meaning cognitive flexibility assessment occurred in one session in which children sorted four different sets of 12 cards by sound and meaning, one set at a time, into a 2 × 2 matrix (see Figure 1), the sound–meaning cognitive flexibility training occurred across five different days, with a different set of word cards each day. The training procedure used the same five sets of words that had been used in the initial assessment (one was the model set and four were the test sets), and children were required to complete two new activities with the cards. On each training day children were first required to perform two successive, one-dimensional sorts of the day's card set, sorting the words into two piles along one dimension (either by meaning or by sound), and then after the cards were placed into one pile again, children were required to sort the cards into two piles along the other dimension. These single sorts highlighted the two dimensions on which the cards could be sorted, fostering children's awareness of the multiple dimensions in the day's word set. Next the children were shown the 2 × 2 matrix, which they recognized from their prior experience with the assessment, and three cards were placed into the matrix, sorted by sound and meaning, leaving one quadrant of the matrix empty. The children were required to choose a card from the remaining nine cards in the set to fill the empty quadrant in the matrix and complete the sound–meaning sort correctly. (See Figure 2 for an example of the matrix completion portion of the training; a correct choice for the empty space could be *bike, bus*, or *boat*. If children selected an inappropriate card for the empty space, the teacher explained a correct choice.) Then the teacher collected the cards and repeated the matrix completion procedure, placing three new cards from the day's card set into the matrix and varying the location of the empty quadrant on each trial. The matrix completion portion of the training continued until each child produced four consecutive successful matrix completions. The training procedure was repeated in its entirety with a different word set on each of five training days (see Cartwright, 2010; and Cartwright et al., 2010, for more information on the assessment and training).

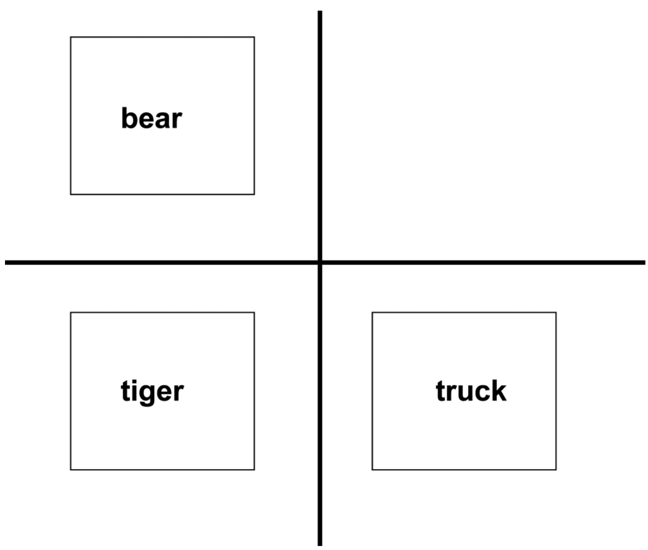

FIGURE 2 An example of the matrix completion portion of the sound–meaning cognitive flexibility training; a correct choice for the empty spot could be *bike, bus,* or *boat.*

Other researchers in China and the United Kingdom have extended this work. For example, Rong and Guo-liang (2006) extended the work to a sample of Chinese schoolchildren and assessed the role of cognitive flexibility in reading comprehension for struggling comprehenders and typical students. In this study cognitive flexibility was assessed with a domain-general task that required children to sort pictures by color and shape, and significant relations emerged between cognitive flexibility, language knowledge, and reading comprehension. Consistent with prior work on poor comprehenders, the struggling readers were significantly less cognitively flexible than their better reading counterparts. These results provide further evidence for the important role of cognitive flexibility in developing reading comprehension.

In addition, in the United Kingdom Yuill and colleagues adapted the sound–meaning cognitive flexibility training for computer administration to pairs of students who were required to collaborate on the task. Children had to work together to complete sorts of words on letter-sound features and meaning, and trained children showed significant improvements in sound–meaning cognitive flexibility, measured with my assessment, described above (Kerawalla, Pearce, Yuill, Luckin, & Harris, 2008; Yuill, Kerawalla, Pearce, Luckin, & Harris, 2008). Yuill and colleagues' observations of children's discussions during the task suggested that the computerized, collaborative task may provide a promising avenue for also improving reading comprehension as well as cognitive flexibility, a possibility they are investigating in future work (N. Yuill, personal communication, March 22, 2007).

What are the implications of this research for children who cannot yet read words? Even before children learn to read, they must be taught that both sounds and meanings are important parts of words. Shared reading experiences and conversations offer opportunities to talk about words' and stories' meanings, and these contexts also offer opportunities to highlight similarities and differences in words' sounds (see Pressley, 2006; and Whitehurst & Lonigan, 1998, for discussions of early literacy experiences that foster children's awareness of sounds and meanings). What is notable for early childhood educators is that sound–meaning cognitive flexibility varies in beginning readers (Cartwright et al., 2010), with higher flexibility associated with better reading comprehension. Even more important is that levels of sound–meaning cognitive flexibility in first- and second-grade beginning readers predict reading comprehension in later elementary school, even when early levels of reading comprehension are controlled (Cartwright, Coppage, & Marshall, 2009). These findings imply that when children begin to read, educators should make sure that they learn the necessary letter-sound information they must have to decode print and also ensure that they learn that books and print convey rich meanings to be enjoyed. In addition, educators should provide multiple opportunities to think and talk about both sounds and meanings to foster children's flexible thinking about these elements of print (for a review of work on reading comprehension in early education, see Shanahan et al., 2010). And for children who still have difficulty coordinating flexibly the sounds and meanings of words, remember that sound–meaning cognitive flexibility can be taught, resulting in improvements in children's cognitive flexibility and reading comprehension (Cartwright, 2002, 2007, 2010).

SUMMARY

In sum, EF provides the means to manage complex cognitive processes, such as reading. And because EF and its associated brain developments parallel reading acquisition, work in EF has profound implications for fostering the successful development of reading skills, including prereading skills, word reading, and reading comprehension. Children who are better able to process flexibly the sounds and meanings of words have more success in the development of reading comprehension. Thus, early child educators should work to provide opportunities for children to learn that spoken and printed words have multiple features, including such things as letters, sounds, and meanings. Instruction that helps children learn to manage the multiple features of spoken and printed language will help ensure that children develop the reading-specific executive functions that will enable them to manage the complexities of reading processes throughout their lives.

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