CHAPTER 13

Development of Executive Function across the Life Span

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Humans have the power to think and do the unexpected. They can generate novel ideas and resist engaging in behaviors strongly elicited by the immediate environment. Broadly defined, *executive function* (EF) abilities are higher cognitive processes necessary for the voluntary control of thought and action. The capacity for cognitive and response control develops slowly across childhood, reaches a peak in early adulthood, and declines in late adulthood. The development of EF abilities is recognized as crucial for daily functioning of individuals in both social and nonsocial realms. EF abilities have been linked to prefrontal cortex development, and injury to this region of the brain not only leads to impairments in EF, but also to devastating loss of function for individuals across a wide range of domains. Viewed in this light, sophisticated EF abilities arguably make humans who they are and make them capable of doing what they do.

No consensus has been reached regarding the specific abilities that are thought to be subsumed under the umbrella term of EF. Moreover, whereas some researchers argue for the unitary nature of a single EF process, others argue for the inclusion of multiple, diverse EF abilities. Although researchers disagree about the inclusion of particular EF processes, most agree that EF skills involve only *higher* level cognitive processes necessary for engaging in complex novel behaviors for which immediate solutions are not obvious and for which flexibility is required in how one might think or act. In this respect, researchers explicitly (e.g., Zelazo, Carter, Reznick, & Frye, 1997) or implicitly (Miller & Cohen, 2001) adopt a problem-solving framework for delineating EF abilities: Thoughts and behaviors that require EF must be intentional, goal directed, and relatively novel. Despite the fact that lower cognitive abilities such as speed of processing (e.g., Case, Kurland, & Goldberg, 1982; Salthouse, 2005; see Hitch, 2006; Park & Payer, 2006, for reviews) and attention (e.g., Jones, Rothbart, & Posner, 2003) have been shown to relate to EF abilities, these abilities are rarely considered EF processes per se (but see Posner & Rothbart, 2007, who view executive attention as an executive control process). This is an important point because difficulties on tasks purported to measure EF abilities may result from either one or multiple EF impairments, or from impairments with simpler lower cognitive processes (cf. Stuss, Shallice, Alexander, & Picton, 1995). In contrast, successful performance on EF tasks necessarily means that all underlying EF processes (and all lower cognitive ones too) must be intact. We reiterate this caution about interpreting EF task difficulties throughout the chapter.

Several abilities have been proposed to constitute EF, including planning, verbal fluency, sequencing, error detection and error correction, self-monitoring, attentional control, and conditional learning. However, many researchers agree that working memory, response control/ inhibition, and set shifting (also known as cognitive flexibility) constitute core EF abilities (Miyake et al., 2000), and that other EF abilities are sometimes considered to be by-products of these core abilities (cf. Diamond, 2006b). For example, planning presumably requires the ability to maintain task-relevant information and the goal in mind (working memory), the ability to consider multiple solutions, including correct ones that temporarily detract from the final goal (cognitive flexibility), and the ability to resist the temptation to respond too hastily or prematurely toward the final goal (response control). As another example, Allain and colleagues (2007) reported that older adults are impaired in their ability to produce temporally coherent sequences, and that their ability to produce such sequences correlates with EF measures on which older adults also do more poorly than younger adults. The authors argued that this link is not surprising, as reproducing temporally coherent sequences depends on being able to keep in mind an internally generated script (working memory), switch back and forth between the script and individual elements (set shifting), and update the script (working memory).

Although specific definitions of working memory, cognitive flexibility, and response control differ somewhat, there is considerable agreement on some of the essential properties of these processes. In brief, working memory generally refers to the temporary maintenance and manipulation of information held online while performing cognitive tasks (Baddeley, 1986, 2003; Hitch, 2006; see also Demetriou, Mouyi, & Spanoudis, Chapter 10 of this volume; Bialystok & Craik, Chapter 7 of this volume; and Ornstein & Light, Chapter 9 of this volume). In turn, cognitive flexibility or set shifting is required when individuals must consider multiple *conflicting* perspectives (or mental sets) on a single object or event (Jacques & Zelazo, 2005b). To be correct on a problem that requires flexibility, individuals must either switch successively between two equivalent perspectives or approach the problem from a less obvious and more difficult perspective, while ignoring a stronger perspective. Problems that require response control—or response inhibition, more specifically—typically require one to overcome the overwhelming tendency to respond in a particular way either because the correct response goes against one's habitual response tendencies or because a particular conflicting response is more strongly suggested by the immediate environment (Verbruggen & Logan, 2008). For example, consider the *object retrieval task* (Diamond, 1990), which requires that infants reach around a transparent barrier (e.g., glass window) to obtain a toy rather than reach directly for it. The object retrieval task is typically viewed as a response control task because to succeed, infants must resist their learned tendency to reach directly for the toy and instead perform a novel, less obvious, and less direct action (i.e., reach around the barrier) to retrieve the desirable object.

This chapter begins with a brief and general overview of major developmental changes that have been documented across the life span in the three core aspects of EF. Following this review of empirical findings, we review theoretical models that have been proposed to account for EF at various points across the life span including early development, normal adulthood, and late adult development. We follow this review of theoretical models by discussing what an idealized integrated developmental model of EF might look like. In doing so, we identify defining characteristics that each process (i.e., working memory, cognitive flexibility, and response inhibition) is likely to possess on the basis of characteristics that have already been identified in different existing models. We then review additional findings documented across the life span in light of this integrated model. We conclude by identifying outstanding issues in the study of EF that any theory of EF will need to address.

DEVELOPMENTAL CHANGES IN EXECUTIVE FUNCTION ACROSS THE LIFE SPAN

Much of the early research into EF processes arose within the neuropsychology literature (e.g., Luria, 1959b; Milner, 1963, 1964) and expanded into the study of psychopathologies such as autism, attention deficit/hyperactivity disorder (ADHD) and conduct disorder in childhood (see Pennington & Ozonoff, 1996, for a review), and schizophrenia in adulthood (Pickup, 2008). Early neuropsychological research equated EF impairments with "frontal lobe impairments" (Stuss et al., 1995) and a "frontal deficit" hypothesis about cognitive declines in late adult development also was proposed (e.g., West, 1996). It is now clear, however, that although frontal function is related to EF, this is not an identity relation. Patients with lesions elsewhere can also demonstrate EF impairments, and not all patients with frontal lobe lesions have EF impairments (see Dick & Overton, 2010; Miyake et al., 2000, for discussions). In recent years, there has been an upsurge of research attempting to map EF processes to specific neurological structural and functional systems (see Zelazo & Lee, Chapter 4 of this volume). Despite the importance of neurophysiological data to our overall understanding of EF, however, we limit our review to psychological and behavioral data on the typical development of EF across the life span.

Research on the development of working memory, cognitive flexibility, and response control is fairly intertwined across much of the life span *within* specific age groups. However, this is not the case across age groups as research on these processes has advanced fairly independently because of the use of different tasks at different ages (see Bialystok & Craik, Chapter 7 of this volume). The high interrelation between cognitive flexibility and response control, in particular, may have arisen, in part, from the fact that the distinction between them can often be blurred (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Garon, Bryson, & Smith, 2008). On the one hand, *cognitive flexibility* is required when individuals must generate and adopt a weaker internal perspective or mental set when it conflicts with another stronger internal perspective or mental set. On the other hand, *response control* is required when the competition is between strong prepotent motor responses elicited either by the presence of strong external cues or by habitual responding (or both) that must be overcome and replaced with a weaker and more novel internally generated response. In other words, difficulties with response control occur at the level of the response itself, whereas difficulties with cognitive flexibility occur at the level of the underlying representation. However, it is unclear whether a particular novel response can be generated in the absence of an underlying associated internal mental set/perspective. For that reason, if an underlying representation is evoked, then any task that requires response control may require cognitive flexibility, although the opposite may not necessarily hold: Cognitive flexibility may be required on some tasks that do not require motor response control.

Moreover, difficulties at either the representation or response level will often lead to the same overt mistaken—and typically, perseverative—response, making it difficult to identify the source of the problem. The only real means of identifying the problem's source is by determining whether individuals who commit an error are aware of their mistake *at the time that they commit it.* If they are aware of their error, then the error likely resulted from an action slip or response control failure. However, if individuals do not recognize an error that they or someone else makes, then they likely err on the basis of an incorrect mental representation or perspective of the problem (cf. Jacques, Zelazo, Kirkham, & Semcesen, 1999).

To compound the issue further, tasks used to assess specific EF processes, including working memory, are particularly challenging because they tend to be complex, requiring several cognitive processes, making it impossible to identify the exact source of any difficulty on these tasks (e.g., Daniels, Toth, & Jacoby, 2006; Delis, Squire, Bihrle, & Massman, 1992; Jacques & Zelazo, 2001; Levine, Stuss, & Milberg, 1995; Miyake et al., 2000; Pennington & Ozonoff, 1996; Stuss & Alexander, 2000; Wiebe, Espy, & Charak, 2008). In fact, most complex EF tasks have working memory, set shifting, and response control requirements, although relative requirements for each vary substantially from task to task. In the *go/no-go task,* for example, participants must press a key in response to one stimulus (go responses) and withhold responding to another stimulus (no-go responses). Researchers have argued about whether performance on no-go trials reflects response inhibition or conflict-monitoring difficulties (e.g., Botvinick et al., 2001).

In another task, the *Wisconsin Card Sort Test* (Berg, 1948; Grant & Berg, 1948), participants are shown four target cards consisting of different geometric shapes (i.e., triangles, circles, stars, and crosses) that also differ in terms of color (red, green, yellow, or blue) and number (1, 2, 3, or 4). They are then presented with test cards that they are required to match with one of the target cards, which can be challenging as the test cards can match multiple target cards on different dimensions. Participants are told on every trial only whether they matched correctly. Once they have sorted by one dimension correctly for 10 consecutive trials, the experimenter surreptitiously changes the dimension, and participants must then switch their response set and attempt to discover the new correct dimension. Participants continue to sort until they complete six categories or until they sort all test cards. Although construed primarily as a measure of set-shifting abilities, the Wisconsin Card Sort Test also has working memory and response control requirements (Dunbar & Sussman, 1995; Milner, 1963; Ozonoff & Strayer, 1997). That is, participants must not only keep the relevant category in mind and update that information when the category changes (i.e., working memory), but they must also resist the temptation to sort cards as they did for previous categories (response control). In addition, successful performance requires other non-EF cognitive processing skills (e.g., learning from feedback). Difficulties on any EF or non-EF abilities will lead to difficulties on this task, making it impossible to identify the source of difficulty.

Similarly, the *A-not-B search task*—an EF measure used with infants—has been construed by different researchers as a measure of working memory (Munakata, 1998), response control (Ahmed & Ruffman, 1998), or both (Diamond, Cruttenden, & Neiderman, 1994; Marcovitch & Zelazo, 2009). In addition, infants may fail to search for a toy at the second hiding location because they are stuck on a representation of the toy's initial hiding location instead of their response to that location, which could reflect set-shifting difficulties (cf. Daniels et al., 2006). The root cause of poor performance on this task is difficult to determine on the basis of performance on the standard version of the task. However, many clever manipulations have been introduced that have allowed researchers to disentangle the relative contributions of specific cognitive processes to performance on this task (see Harris, 1987; Marcovitch & Zelazo, 2009, for reviews).

Despite limitations in our ability to differentiate between EF processes on most EF tasks, a great deal is known about the development of EF across the life span. The following sections review common tasks used to assess EF processes at different points in development and general age-related changes documented from the use of these tasks.

Executive Function Development in Infancy

Assessing cognitive development, in particular, EF, in infants is inherently challenging because of limitations in symbolic processing (including language) and restrictions in response execution. Despite these shortcomings, we know a surprising amount about EF in the first 2 years of life. Nonetheless, as discussed in the previous section, EF tasks typically confound various components, and most require a combination of response inhibition, working memory, and set shifting to complete successfully. Tasks developed to assess EF processes in infancy are no exception. In fact, the inability to separate EF components in tasks targeted at infants may be partly responsible for considering EF as a unitary structure, particularly in the first 6 years of life (Wiebe et al., 2008).

Search tasks that require infants to search for objects hidden in one of multiple locations are important paradigms for studying EF in infancy. One of the simplest—the *delayed response* (or *delayed reaction*) task—involves an object that is conspicuously hidden in one location. After a delay, infants are allowed to search for it (Hunter, 1913, 1917). Typically, the task is repeated for a number of trials at different locations following a predetermined order. Success on this task correlates with activation of the dorsolateral prefrontal cortex (see Fuster, 1980; Goldman-Rakic, 1987; Jacobsen, 1936), and the task is often considered to be a measure of working memory (Reznick, Morrow, Goldman, & Snyder, 2004). Diamond and Doar (1989), for example, found improvements on this task between 6 and 12 months of age, with older children capable of tolerating longer delays than younger children (roughly 2.1 seconds per month). Errors on the delayed response task are typically perseverative in nature in that infants have a bias to search at previously searched locations (Diamond & Doar; Smith, Thelen, Titzer, & McLin, 1999).

A common variant of the delayed response task inspired by Piaget (1954)—and less commonly known, by Luria (1959a)—is the A-not-B task mentioned earlier. In this task, an object is hidden repeatedly at one location (A) for a number of trials and then switched to another location (B). Infants often commit the *A-not-B error*, which consists of perseverative responses at location A on B trials. Two separate meta-analyses (Marcovitch & Zelazo, 1999; Wellman, Cross, & Bartsch, 1986) have confirmed the robustness of this phenomenon and identified a number of variables that are associated with the likelihood that A-not-B errors will occur, including age (Sophian & Wellman, 1983), delay (Gratch, Appel, Evans, LeCompte, & Wright, 1974), distance between hiding locations (Horobin & Acredolo, 1986), number of hiding locations (Cummings & Bjork, 1983; Diamond et al., 1994), and number of A trials (Marcovitch, Zelazo, & Schmuckler, 2002).

Remarkably, researchers have demonstrated that hiding the object from view is not required to elicit the A-not-B error, indicating the relative importance of motor habits to performance on this task (Clearfield, Diedrich, Smith, & Thelen, 2006; Clearfield, Dineva, Smith, Diedrich, & Thelen, 2009; Smith et al., 1999; but see Munakata, 1997 for an alternative interpretation). For example, using a version of the A-not-B task in which the object remained visible, Clearfield et al. (2006) assessed perseverative responding in infants who were not yet able to search for *hidden* objects. They showed that perseverative reaching was most likely at 8 months of age but surprisingly less likely to occur at younger ages. They explained this counterintuitive finding by proposing that infants first must establish stable reaching patterns before they can develop potent motor habits.

Consistent with the importance of reaching dynamics, several studies have revealed that infants who only see the object hidden at A outperform infants who reach for the object at A (Ahmed & Ruffman, 1998; Hofstadter & Reznick, 1996; see Munakata, McClelland, Johnson, & Siegler, 1997, for an explanation using a graded representations account). However, using a repeated-measures design with a different coding scheme, Bell and Adams (1999) demonstrated comparable performance on reaching and looking versions of the A-not-B task at 8 months of age (see also Matthews, Ellis, & Nelson, 1996), suggesting that difficulties on the A-not-B extend beyond simple motor response perseveration. Although better performance seems possible with looking-time paradigms than with reaching paradigms, Bell and Adams' results provide evidence that looking-time paradigms can still reliably be used as an assessment of the A-not-B error, making this version particularly useful for neurophysiological studies (Bell, 2001).

Recently, a new and potentially very informative variant of the A-not-B task has been developed for use with infants capable of walking. Using a *locomotor A-not-B task* with 13-month-old infants, Berger (2004) found that all infants in a baseline condition could walk down one flat path and then walk down a different flat path. In contrast, when infants had to walk down paths that involved descending staircases instead of flat paths, 25% of infants went back to the original A staircase on B trials instead of descending the new B staircase. This marked difference in behavior is most likely attributed to additional cognitive demands required for infants of this age to descend staircases as opposed to traversing on flat ground, suggesting that limiting available cognitive resources increases perseverative responding.

Another popular paradigm used to assess EF in infancy, the *delayed nonmatching/matching to sample task,* also capitalizes on delayed responding. In this paradigm, participants are shown an object and then required to choose between it and a novel object after a brief delay. Participants are either rewarded for selecting the previously seen (delayed matching) or the novel (delayed nonmatching) object. Overman (1990) tested infants on both tasks and found: (1) infants learn the delayed nonmatching version significantly faster than the delayed matching one, and (2) performance on both versions improves with age.

Both the delayed matching and nonmatching to sample versions of the task make EF demands because they require working memory and response inhibition; the previously seen object must be kept in mind and infants must inhibit selecting a particular type of object (either the familiar or novel one). However, Diamond, Churchland, Cruess, and Kirkham (1999) argued that young infants' (under 21 months) difficulty with this task lies in their inability to understand the relation between the stimulus and reward. Specifically, in the standard task (as used by Overman, 1990), a reward is hidden under the correct object. However, Diamond et al. (1999) showed that infants as young as 9 months of age demonstrate remarkable improvement when the reward is physically attached to the object or when verbal praise is used instead of a tangible reward. On the basis of these findings, Diamond (2006a) argued that infants' difficulty with the standard version of the task results from a difficulty with grasping the conceptual connection between the physically unconnected stimulus and reward, and not necessarily with the particular working memory or response control demands of the task.

Another important EF task used with infants that requires them to inhibit a prepotent response is the object retrieval task popularized by Diamond (1990) and mentioned previously. In this task, a desirable object is visible through a transparent box with one opening on one of the sides. To obtain the object, infants must inhibit their tendency to reach directly for the object and instead detour around to the open side. On the basis of a longitudinal study, Diamond reported that 6.5- to 7-month-olds unsuccessfully attempt to retrieve the toy through the closed side facing them. In contrast, 7.5- to 8-month-olds try to change their body position or the box position so that the open side is in line with their reach. The first clear evidence that infants can reach for an opening not directly in their line of sight occurs between 8.5 and 9 months, although infants still need to look through the opening at some point, often resulting in awkward reaches. Between 9.5 and 10.5 months, infants can retrieve a toy without needing to look through the opening.

Executive Function Development in Preschoolers

A panoply of tasks have been developed to assess various aspects of EF in preschoolers (e.g., Carlson, 2005), although we review only a handful here because developmental changes across many of these tasks, especially tasks assessing cognitive flexibility, tend to be similar. In particular, major age-related changes in EF have been noted to occur between 3 and 5 years of age across an impressive array of tasks assessing various EF abilities (for more extensive reviews, see Diamond, 2006b; Garon et al., 2008; Jacques & Zelazo, 2005b; Zelazo et al., 1997; Zelazo & Jacques, 1997).

For example, the *Dimensional Change Card Sort* was developed to assess children's abilities to sort the same cards successively using two incompatible sets of rules (Frye, Zelazo, & Palfai, 1995; Zelazo, 2006; Zelazo, Müller, Frye, & Marcovitch, 2003). In the standard version of this task, preschoolers are presented with test cards that vary on two dimensions (e.g., color and shape) and are asked to sort the cards according to one dimension and then the other. Children are presented with two sorting trays, each depicting a target card that matches each test card on exactly one dimension. For example, if test cards consist of red trucks and blue flowers, then target cards consist of a red flower and a blue truck. Three-year-olds have no difficulties sorting test cards by a first dimension (either color or shape), whatever that dimension happens to be. However, most 3-year-olds fail the *postswitch phase* of the standard version of this task by perseverating and continuing to sort by the preswitch dimension, whereas the majority of 4-year-olds and most 5-year-olds sort the cards correctly by both sets of rules.

Several other tasks developed to assess cognitive flexibility at this age share the same underlying task structure such that children must respond in one way on the basis of one mental set/perspective and then respond in a different, conflicting way on the basis of a different mental set/perspective. In *deductive* versions of such tasks, including the Dimension Change Card Sort (Frye et al., 1995), the *synonym judgment task* (Doherty & Perner, 1998), and the *physical causality task* (Frye, Zelazo, Brooks, & Samuels, 1996), the experimenter tells children explicitly how to respond according to each mental set, whereas in *inductive* versions, including the *discrimination-shift learning paradigm* (Kendler & Kendler, 1961), the *double categorization task* (Blaye & Jacques, 2009), the *false belief task* (Wimmer & Perner, 1983), the *Flexible Item Selection Task* (Jacques & Zelazo, 2001), the *matrix classification task* (Inhelder & Piaget, 1959/1964), and the *novel word inference task* (Deák, 2000), children must infer how to solve at least one aspect of the task (see Jacques & Zelazo, 2005b, for more discussion on the distinction between deductive and inductive tasks).

For example, in the Flexible Item Selection Task (Jacques & Zelazo, 2001), children are shown three items on each trial (e.g., a small red boat, a small blue boat, and a large blue boat). Two of the items match on a specific dimension (e.g., size) and two items match on another dimension (e.g., color). A third dimension is constant across the three items (e.g., shape). Thus, on all trials, one of the items, the *pivot* item (the small blue boat) matches one of the other items on one dimension and the remaining item on the alternate dimension. Children are asked to select a pair of matching items, and then immediately switch and select a different pair that matches on another dimension. Consequently, to succeed, they must be flexible in how they represent the pivot item so that they can select it twice, according to two different dimensions. Unlike the Dimensional Change Card Sort, the Flexible Item Selection Task is an inductive task because children are not told the matching dimensions; they must determine these for themselves. Research with the Flexible Item Selection Task has shown that the majority of 3-year-olds perform worse than both 4- and 5-year-olds on their first selection, suggesting that the inductive nature of the task is especially difficult for them. In contrast, 4-year-olds do well on their first selection but perform worse than 5-year-olds on their second selection, indicating that they have specific difficulties with the switching aspect of the task.

As another example, although initially designed to assess children's understanding of the subjective nature of mental states, *false-belief tasks* are believed to have strong EF requirements and correlate strongly with performance on traditional EF tasks (e.g., Carlson & Moses, 2001; Carlson, Moses, & Hix, 1998; Frye et al., 1995; Hughes, 1998; Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991; Zelazo, Jacques, Burack, & Frye, 2002; see Perner & Lang, 1999, for a review). Specifically, in false-belief tasks, children are asked to predict the behavior of a protagonist who holds a mistaken belief about the whereabouts of an object or the contents of a container when they themselves know the real location of the object or contents of the container. Hence, to succeed, children must reason from the erroneous perspective of the protagonist and refrain from responding on the basis of their own reality-informed perspective, thereby requiring cognitive flexibility. Research with the false-belief task has shown age-related changes between 3 and 5 years of age in children's ability to predict the behavior of the protagonist correctly (see Carpendale & Lewis, Chapter 17 of this volume; Chandler & Birch, Chapter 19 of this volume; Wellman, Cross, & Watson, 2001, for reviews).

In short, performance on many measures believed to assess cognitive flexibility suggest that 3- and 4-year-olds often experience difficulty, even though 4-year-olds do better on some tasks (especially deductive tasks) than 3-year-olds. Inductive tasks are often solved later than deductive ones, perhaps as a result of the added difficulty of having to infer what to do (see Jacques & Zelazo, 2005b, for a review). However, deductive and inductive tasks also tend to differ in terms of the amount of relevant information that is explicitly *labeled.* Specifically, in the course of telling children what to do, researchers generally label all relevant information in deductive tasks. In contrast, because children are not told explicitly what to do on inductive measures, whether relevant information gets labeled in inductive measures is more variable. As discussed later in this chapter, labeling has a significant impact on performance on measures of cognitive flexibility.

Two types of response control tasks are used with preschoolers, including tasks that assess children's ability to delay their behavior (referred to by Garon et al., 2008, as simple response inhibition tasks) and tasks that require children to inhibit a dominant response while generating a novel response that goes against their existing response tendency. The latter of these tasks used within the preschool period are similar in structure to deductive versions of cognitive flexibility measures, although instead of requiring that children switch between two mental sets that they are taught during the task itself, children are asked to solve a problem that requires them to respond to stimuli in a manner that goes against their preexisting, pre-experimental response tendencies (e.g., the *Interference Control Task,* Müller, Zelazo, Hood, Leone, & Rohrer, 2004; the go/no-go task, Luria, 1959a, 1961; *Bear/Dragon Task,* Reed, Pien, & Rothbart, 1984; *Day-night Stroop-like Test,* Gerstadt, Hong, & Diamond, 1994; Passler, Isaac, & Hynd, 1985; *Detour-Reaching Box,* Hughes & Russell, 1993; *Luria Hand Game,* Hughes, 1996, 1998; *Luria Tapping Game Test,* Diamond & Taylor, 1996; *Deceptive Pointing Task,* Carlson et al., 1998; *Simple Simon Task,* Jones et al., 2003; Reed et al., 1984). For example, in the Day-night Stroop-like task (Gerstadt et al., 1994), children are asked to say "Day" when presented with a picture of a moon and "Night" when presented with a picture of a sun. To succeed, then, children must inhibit their preexisting tendency to respond in a semantically congruent fashion to each stimulus (e.g., to say "Day" in response to the picture of the sun).

Some debate exists as to whether these response inhibition tasks, referred to by some researchers as conflict inhibition tasks (Carlson & Moses, 2001) or complex response inhibition tasks (Garon et al., 2008), really differ from tasks assessing cognitive flexibility (see Jacques & Zelazo, 2005b), or what Garon et al. refer to as response–set-shifting tasks. In particular, preschoolers' performance on both types of tasks correlates well and follows a similar developmental path (e.g., Carlson & Moses, 2001; Carlson et al., 1998; Frye et al., 1995; see Perner & Lang, 1999; Zelazo & Jacques, 1997, for reviews). In addition, as discussed previously, difficulties on these purported response inhibition tasks could easily result from difficulties with switching between two relevant underlying mental sets (i.e., switching from a preexisting mental set to one introduced within the experiment) rather than between overt response sets. Conversely, poor performance on cognitive flexibility tasks could be caused by difficulties with response switching instead of switching between mental sets (but see Jacques et al., 1999, for evidence against such an account of difficulties on the Dimensional Change Card Sort).

Developmental changes on delay tasks, which require children to delay or modulate a prepotent response, follow a different developmental path (Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002; Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Reed et al., 1984; Vaughn, Kopp, & Krakow, 1984). There are two general kinds of delay tasks: simple delay tasks and choice delay tasks. In simple delay task, children must resist the temptation to respond before they are allowed, or they must slow down or modulate a motor activity. In choice delay tasks, such as the *delay of gratification task* (Mischel, Shoda, & Rodriguez, 1989), children are given a choice between responding immediately for a smaller reward or delaying their response to get a larger reward. On simple delay tasks, by 4 years of age, children are capable of holding a candy on their tongue without eating it, or resisting peeking at an experimenter who noisily wraps a gift (Kochanska et al., 1996). On choice delay tasks, same-aged children can also choose to wait for a larger prize instead of receiving a smaller prize immediately (Mischel et al., 1989; Thompson, Barresi, & Moore, 1997). In fact, even 3-year-olds can choose to delay responding for a larger reward for a third person even though they do not do so for themselves at this age (Prencipe & Zelazo, 2005).

As described previously, working memory in infants and young children is often assessed using delayed response tasks (Reznick et al., 2004). For preschoolers, however, different tasks are used to assess working memory. In particular, researchers differentiate working memory tasks into two groups: simple and complex tasks (see Hitch, 2006, for a review). *Simple working memory tasks,* also referred to as *short-term memory tasks,* require only holding information in mind over a delay, whereas *complex working memory tasks* require holding temporary information in mind and manipulating or updating it in some way. Complex working memory tasks in particular are associated with EF, especially beyond the infancy period. As an example of a simple working memory task, Alp (1994) devised an imitation sorting task for use with children in the transition from infancy through the early preschool years. He assessed 12- to 36-month-olds on a task in which children had to imitate an experimenter sorting objects into different containers. The highest number of objects that children sorted correctly was taken as an index of their working memory size. Alp found linear increases in working memory during this period, with age accounting for 55% of the variance in working memory.

Complex working memory tasks also have been devised to assess preschool children's abilities to hold information in mind while processing it in some way. For example, on the basis of Petrides and Milner's (1982) self-ordered pointing task designed for use with adults, Hughes (1998) used a working memory task in which children were required to update their still-to-be-remembered list on each trial. Hughes showed children a spin-the-pots task in which they retrieved rewards that were hidden under eight different pots. Only one reward was hidden under each pot, and between trials, the pots were scrambled and spun. Moreover, on each trial, children were reminded to choose a pot that they had not yet selected. Thus, to succeed, children needed to update their list of searched and still-to-be searched locations, and as a result, they had to process information in addition to remembering it. Hughes found that the majority of 3-year-olds succeeded on this task.

Executive Function Development in School-Aged Children, Adolescents, and Young Adults

A radical change occurs in the assessment of EF during the school-age period. Performance on EF tasks used with preschool children tends to be scored in terms of accuracy because children are generally correct or incorrect (and often perseverative) on individual trials. With school-aged children, however, it is more common to use age-appropriate versions of adult tasks in which the correct answer is expected and EF efficiency is instead inferred from slowed response times indicating increased difficulty (although accuracy is sometimes used with school-aged children and beyond; e.g., see work by Zelazo, Craik, & Booth, 2004). For this reason, this section reviews performance of school-aged children and adolescents in relation to performance of young adults, who tend to show peak reaction time performance on these EF tasks. In general, performance on EF tasks tends to improve with age for children and adolescents relative to young adults, but then declines again in older adults (see next section). Moreover, like preschoolers (but unlike infants), EF tasks used within these age ranges are often purported to assess specific EF abilities, including cognitive flexibility or set shifting (sometimes referred to as task switching; Allport, Styles, & Hsieh, 1994; Monsell, 2003), response inhibition, and working memory (sometimes referred to as information updating and monitoring; Miyake et al., 2000).

Set shifting has been assessed effectively with school-aged children and adults using card sorting tasks, like the Wisconsin Card Sorting Test (Berg, 1948; Grant & Berg, 1948) described earlier, and task-switching paradigms (Monsell, 2003). In task-switching paradigms, participants are required to switch between two simple tasks, such as adding and subtracting numbers (e.g., Baddeley, Chincotta, & Adlam, 2001). Participants are generally slower immediately after a switch, known as the switch cost (Monsell, 2003). Studies using the Wisconsin Card Sorting Test and other set-shifting tasks (Cepeda, Kramer, & Gonzalez de Sather, 2001; Chelune & Baer, 1986; Crone, Bunge, van der Molen, & Ridderinkhof, 2006; Levin et al., 1991; Passler et al., 1985; Welsh, Pennington, & Groisser, 1991) have found that younger children have difficulty with set shifting but improve throughout the school years. In general, age-related increases have been identified from school-aged children to young adults, although specific ages at which tasks show the most increase and at which performance plateaus vary substantially between tasks.

A number of response inhibition tasks have been used with school-aged children and adults, including most commonly, the *Stroop test* and analogous *spatial Simon task,* the *antisaccade task,* the *flanker task,* modified *Simon Says* paradigms, as well as the go/no-go task and the related *stop-signal paradigm.* In the classic Stroop test (Bub, Masson, & Lalonde, 2006; Comalli, Wapner, & Werner, 1962; Stroop, 1935; see MacLeod, 1991, for a review), participants are presented with a list of color words (e.g., "red," "blue," "green") printed in nonmatching ink colors (e.g., blue, green, red, respectively). They are asked to inhibit reading the word and instead name the color of the ink as fast as possible. Similarly, in the Simon task (Lu & Proctor, 1995; Simon, 1990), participants must respond using one of two keys (one key on the left and one key on the right) on the basis of the direction to which an arrow is pointing (left or right), while ignoring the irrelevant position on the screen in which the arrow appears. In one version used with preschoolers (Gerardi-Caulton, 2000) and school-aged children (Davidson, Amso, Anderson, & Diamond, 2006), children are instructed instead to press the left button in response to one animal and the right button in response to another animal. Crucial incongruent trials occur when stimuli appear spatially over the incorrect response key and participants must inhibit their tendency to respond with that key. In Simon Says tasks (LaVoie, Anderson, Fraze, & Johnson, 1981; Strommen, 1973), children are told simple commands ("Touch your nose!"). They are to obey these commands, but only if these are prefaced by the words "Simon says." As a result, on some trials when "Simon says" is not stated explicitly, children must inhibit direct requests to respond to a command to which they would normally respond. Antisaccade tasks require participants to look away from a target as soon as it appears, thereby requiring inhibition of the tendency to look toward an appearing object (Munoz, Broughton, Goldring, & Armstrong, 1998). Flanker tasks (Eriksen & Schultz, 1979) are computerized tasks in which participants are shown a central stimulus on a screen about which they must make a judgment (e.g., decide whether an arrow is pointing left or right). The central stimulus is flanked by or surrounded by other stimuli that are either all congruent or incongruent with it (e.g., same or opposite pointing arrows, respectively). Any difference in reaction time for trials with congruent and incongruent trials is taken as evidence of inhibition difficulties. Finally, in the go/no-go task (e.g., Lamm, Zelazo, & Lewis, 2006; Luria, 1959a), and one of its variants, the stop-signal paradigm (Schachar & Logan, 1990; Schachar, Tannock, & Logan, 1993; van den Wildenberg & van der Molen, 2004; Williams, Ponesse, Schachar, Logan, & Tannock, 1999), participants are required to respond on most trials except under specific circumstances (e.g., a specific stimulus is presented), at which point they must inhibit their responses despite having built up a strong tendency to respond. Like measures of set shifting, performance on all of these tasks varies during the elementary school years (and in some cases, during the preschool and adolescent years as well), but generally improves with age.

Although many complex working memory span tasks exist for use with school-aged children and beyond, such as operational, reading, counting, and visual pattern span tasks, they share similar underlying methodologies even though they differ in terms of the information retained and the specific processing operations required (see Bialystok & Craik, Chapter 7 of this volume; Hitch, 2006, for a review). Specifically, in complex memory span tasks, participants are required to perform a secondary processing task (e.g., solving math equations) while keeping temporary information associated with the primary task (e.g., the answers to the equations) active in working memory. Complex working memory span is the maximum amount of information participants remember while still effectively performing the processing task (Towse & Hitch, 2007). Case et al. (1982), for example, used a counting span task in which 6- to 12-year-old children counted objects while remembering the total number on each card. They found that age-related differences in counting span was associated with age-related changes in counting efficiency.

Executive Function Development in Older Adults

After reaching peak levels during the young adult years, both performance on cognitive tasks generally, and EF tasks specifically, decline during the late adult years (Mayr & Kliegl, 1993; Touron & Hertzog, 2004; Verhaegen, Kliegl, & Mayr, 1997). These declines have been associated with changes in the prefrontal cortex, specifically the dorsolateral region (Phillips & Della Sala, 1999), resulting in a loss of efficiency in inhibition processes (Albert & Kaplan, 1980; Dempster, 1992, 1993, 1995; Hasher & Zacks, 1988, see Daniels et al., 2006; Phillips & Della Sala, 1999; West, 1996, for reviews). Indeed, there is a greater reduction in the volume of frontal cortex relative to other neural regions in older adults (Haug & Eggers, 1991), and typical neurological changes are associated with increases in perseverative behavior and distractibility.

Lowered EF performance in older adults can be seen across a wide range of contexts including performance on EF tasks themselves, such as the *Wisconsin Card Sorting Task* (Axelrod & Henry, 1992; Daigneault, Braun, & Whitaker, 1992; Libon et al., 1994), problem-solving tasks (Della Sala & Logie, 1998; Shallice & Burgess, 1991), letter fluency (Whelihan & Lesher, 1985), *Tower of London* (Allamanno, Della Sala, Laiacona, Pasetti, & Spinnler, 1987), garden-path sentences (Hartman & Hasher, 1991), visual self-ordered retrieval task (Daigneault & Braun, 1993), temporal-order judgments (Allain et al., 2007; Moscovitch & Winocur, 1995), context processing (i.e., the AX-CPT task; Rush, Barch, & Braver, 2006), and directed forgetting (Zacks, Radvansky, & Hasher, 1996). An example of this age-related decline is evident in prospective memory tasks. In one such task, participants are given instructions to do something in the future either after a certain delay (time based) or when exposed to a cue (event based). Successful performance requires the ability to switch flexibly between attending to the current task and monitoring the appropriateness of engaging in the prospective task, and inhibiting the current task when executing the prospective task. Older adults are less accurate in time-based tasks relative to younger adults (McDaniel & Einstein, 1992; but see Patten & Meit, 1993), and show deficits in event-based tasks with increased complexity (e.g., needing to remember four cues instead of one; Einstein, Holland, McDaniel, & Guynn, 1992) and atypical cues (Mäntylä, 1994).

Life-span studies using set-shifting tasks also have revealed inverted-U–shaped developmental changes with improvements from the school age to the younger adult period and then subsequent declines in the late adult developmental period (Cepeda et al., 2001; Kray, Eber, & Lindenberger, 2004; Mayr, 2001; Reimers & Maylor, 2005; Zelazo et al., 2004). For example, Zelazo et al. (2004) used a modified version of the *Dimensional Change Card Sort* with school-aged children, young adults, and older adults. In this version, participants had to "sort" computerized cards according to either shape or color of the stimuli, but alternate between sorting dimensions from trial to trial depending on the presence or absence of a border surrounding the stimuli. Zelazo et al. found that both school-aged children and older adults between 65 and 75 years of age found the task more challenging than younger adults.

Response inhibition difficulties are also evident on the *Stroop task,* with slower color naming compared with baseline for older adults (Boone, Miller, Lesser, Hill, & D'Elia, 1990; Cohn, Dustman, & Bradford, 1984; Comalli et al., 1962; Daigneault et al., 1992; Houx, Jolles, & Vreeling, 1993), although these deficits are minimal in highly educated adults (Houx et al., 1993) or when color and word information are separated spatially (Hartley, 1993). Paradoxically, decreases in response inhibition can sometimes lead to task improvements. For example, older adults do not exhibit negative priming, the tendency to suppress previously unnecessary material, because of reductions in response inhibition (Hasher, Stoltzfus, Zacks, & Rypma, 1991). Finally, whereas simple working memory performance tends to stay relatively stable with advancing age, complex working memory performance decreases, beginning as early as the 20s, although there is some debate as to whether verbal and visuospatial working memory decline at the same rates (see Park & Payer, 2006, for a review).

THEORETICAL MODELS OF EXECUTIVE FUNCTION

Several models of EF have been proposed to account for the development of EF at various points of the life span. Existing models of EF generally fall under two broad types: On the one hand, *representational models* focus on the kind of representations individuals can hold and the ensuing executive control made possible by these representational abilities (e.g., Figure 13.1); on the other hand, *componential models* see EF as consisting of a group of more-or-less correlated, yet separable cognitive processes that work together to produce executive control (e.g., Figure 13.2). As mentioned previously, there is also a more common distinction made in the literature between unified and diverse models of EF, and although this distinction overlaps somewhat with the representational/componential distinction that we make here, they are not identical. Proponents of unified models (loosely related to representational models) claim that there is a single unified EF process that underlies cognitive and response control, whereas diverse models (related to componential models) suggest that there are multiple dissociable EF processes. Although diverse and componential models are essentially the same, there are unified models that are not representational; for example, models that invoke a single construct (e.g., a general purpose inhibitory mechanism) to account for EF processes assume a single unified process, but such models need not be representational.

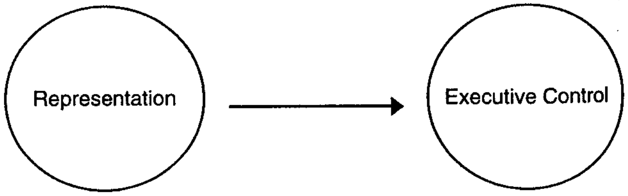

Figure 13.1 Representational models stipulate that *how* information is represented influences executive control.

Representational Models

Childhood Representational Models

One of the earliest developmental models of cognitive and behavioral control was proposed by Vygotsky (1929) in the 1920s, and later tested empirically and expanded on by his colleague Luria—although at that time, these abilities had not been grouped under the modern EF umbrella term. In his sociocultural theory of cognitive development,

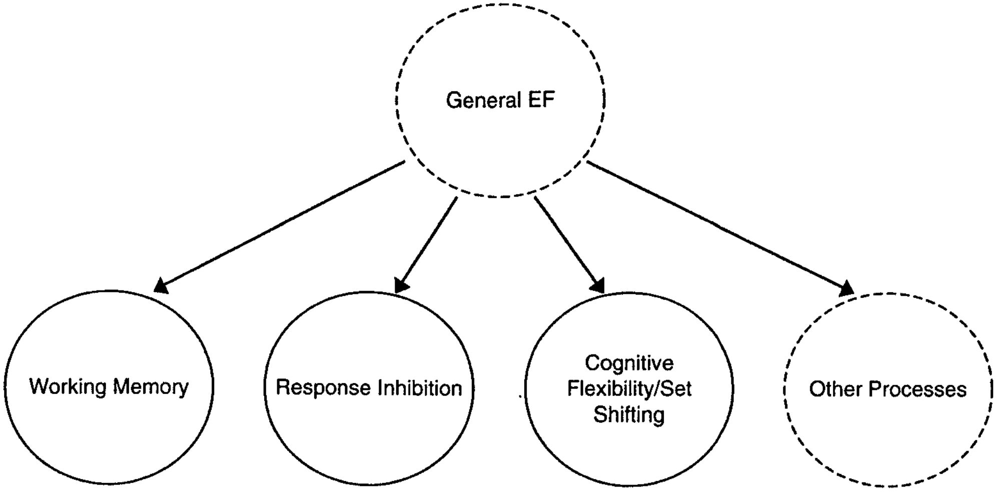

Figure 13.2 Componential models. Most componential models tend to include working memory, response inhibition, and cognitive flexibility/set shifting. Some models include a more general executive function (EF) process, other specific processes, or both (*dashed circles*).

Vygotsky theorized that socially transmitted cultural tools, particularly language, allow for qualitative changes in the structure of human cognition making the voluntary control of behavior possible (Luria, 1969, 1976; Vygotsky, 1978, 1934/1986). In particular, he stated that the "specifically human capacity for language enables children to provide for auxiliary tool in the solution of difficult tasks, to overcome impulsive action, to plan a solution to a problem prior to its execution, and to master their own behavior" (Vygotsky, 1978, p. 28). From our modern perspective, then, Vygotsky viewed the development of EF as rooted in the development of language.

A central tenet of Vygotsky's theory was his belief that cognitive change first manifests itself in social exchanges (interpersonal) and only later becomes internalized by the individual (intrapersonal; Luria, 1961; Vygotsky, 1978). A second fundamental principle in Vygotsky's theory concerned the determining role of speech in the organization of higher psychological processes (Vygotsky, 1978). He proposed that speech and thought first develop independently only to become tightly intertwined in the course of development (Vygotsky, 1929, 1978). Initially, speech serves only a communicative purpose, but later acquires other functions such as semantic, syntactic, and for our purposes, directive functions (Luria, 1957, 1969, 1976). Vygotsky claimed that the emergent directive function of speech allows children to organize and plan their behavior, essentially rendering them capable of voluntary, purposeful behavior (Vygotsky, 1978, 1934/1986). Vygotsky's untimely death prevented him from conducting much of the experimental research required to test his theory. However, his colleagues—Luria, in particular—conducted empirical studies that tested various aspects of Vygotsky's claims. The results of these experiments allowed Luria to refine and elaborate on Vygotsky's initial theory (e.g., Luria, 1957, 1959a, 1961, 1969).

A key finding in Luria's experimental work was the progressive developmental changes he identified in children's ability to govern their behavior via external and then internal speech or verbal directives (e.g., Luria, 1959a, 1961). More specifically, Luria not only found evidence that infants and preschoolers are able to obey increasingly complex verbal commands with development, but that children younger than 3 years find it more difficult to *inhibit* responses according to verbal instructions than to initiate them (see later in this chapter for experimental details). He further argued that without speech, stimulus-response mappings are extremely inflexible and can be changed only gradually (Luria, 1957). Thus, on both Luria and Vygotsky's account, the advent of language increasingly allows children greater cognitive and response control as they develop. The medium of language provides the vehicle for representing information in the form of self- or other-generated verbal directives that allow children to control their thoughts and behaviors, and developmental changes in control result from developmental changes in language abilities.

A second, more recent representational model of the early development of EF has been elaborated by Zelazo and his colleagues. They take a functional approach to the study of EF, defining the construct by what it accomplishes (Zelazo et al., 1997; Zelazo et al., 2003). From this perspective, Zelazo et al. (1997) presented a problem-solving approach to the study of EF that involves the subfunctions of problem representation, planning, execution, and evaluation; EF impairments can manifest themselves at any of these stages. From Zelazo and colleagues' perspective, increases in representational skills, which most likely are linked to maturation of the prefrontal cortex, account for developmental changes in EF. Three separate, but related, models have been proposed to describe the development of EF at different levels of analyses: levels of consciousness model, hierarchical competing systems model, and cognitive complexity and control theory.

According to the levels of consciousness model (Zelazo, 2004), an intentional representation is formed when an object becomes the content of consciousness. In the simplest case, the object is an external stimulus that triggers a description from semantic memory. This basic process is referred to as minimal consciousness and is thought to be active early in life, perhaps even innate. Reflection occurs when a representation itself becomes the content of consciousness. This allows for memory to be decoupled from experience. The memory can now serve as a goal even in the absence of the original object. Furthermore, reflection is a recursive process such that a level of reflection can then become the object of a representation, resulting in a second-order reflection, and so on. The representational capability of a system is related directly to the highest degree of reflection that is possible.

Focusing on the importance of the development of the representational system, the hierarchical competing systems model (Marcovitch & Zelazo, 2006, 2009) posits that the ability to reflect is a primary determinant of executive control (see Mascolo & Fischer, Chapter 6 of this volume, for an extended discussion of the development of levels of reflection). According to the hierarchical competing systems model, behavior is jointly determined by a habit system that biases responding toward previously rewarded behaviors and a representational system that has the potential to override the habit system via reflection. Thus, EF errors occur in the absence of reflection, which is common in the face of complex or distracting stimuli. One important corollary of the hierarchical competing systems model is the role of task experience, which paradoxically increases the likelihood of repeating previously successful behaviors via the habit system, as well as the likelihood of reflection via the representational system. Consequently, U-shaped relations are observed between EF performance and the amount of experience with the task. Errors are rarely made with little task experience because of a weak habit system or with large amounts of task experience (see Esposito, 1975, for a review of overtraining effects on the discrimination-shift learning paradigm) because reflection becomes likely. Rather, errors are most likely to occur when there is a moderate amount of experience such that the habit system is relatively strong but reflection is not elicited (Marcovitch & Zelazo, 2000, 2006).

High levels of reflection also allow for increases in representational flexibility. According to the cognitive complexity and control theory (CCC, Zelazo & Frye, 1998; CCC-r, Zelazo et al., 2003), behaviors are the products of mentally represented "if-then" rules. Furthermore, age-related advances in levels of reflection are responsible for age-related changes in the level of complexity of the rule structures that children can represent and follow. Specifically, 2.5-year-old children can follow one rule (Zelazo & Reznick, 1991; Zelazo, Reznick, & Piñon, 1995), 3-year-old children can follow a pair of compatible rules, and 5-year-old children can switch between two pairs of incompatible rules (Frye et al., 1995).

Munakata and colleagues also propose a representational model for EF; however, they take the perspective that the strength of representations is critical to solving EF tasks (Cepeda & Munakata, 2007; Morton & Munakata, 2002; Munakata, 2001). By postulating that representations are graded in nature (i.e., some are stronger than others), Munakata (2001) offers a parsimonious explanation for dissociations in behavior, which are common in the EF literature. For example, behavioral dissociations, such as the finding that 8- to 12-month-old infants who search incorrectly for an object are surprised when they observe someone else search incorrectly (Ahmed & Ruffman, 1998), are often explained by proposing separable knowledge systems (e.g., coordination of a means-end routine vs. object permanence) that are assessed using different methods (e.g., reaching vs. looking). According to Munakata (2001), however, dissociations can be explained by the fact that different methods of assessment require different strengths in representations. For example, because their representations of hidden objects are graded, younger infants are more successful at demonstrating their representation of a hidden object on tasks that only require responses that depend on weaker representations, such as looking, than on those that require responses that depend on stronger representations, such as reaching.

The active/latent account put forth by Munakata and colleagues (Cepeda & Munakata, 2007; Morton & Munakata, 2002; Munakata, 1998) emphasizes the importance of representational strength in EF. Active traces, subserved by the prefrontal cortex, involve the maintenance of a representation over a delay. In contrast, latent traces subserved by the posterior cortex contain previously relevant information and arise from repeatedly processing stimuli. Like others, Munakata and colleagues argue that prefrontal active representations code more conceptual, abstract representations, whereas posterior latent representations code stimulus-specific representations. Behavior is determined by the relative strengths of active and latent traces, and failures in EF occur when active traces are not strong enough to compete with latent traces. More important, as the strength of active traces increases with development of the prefrontal cortex, so does the ability to maintain the relevant representation, increasing the capacity for flexible behavior.

Adulthood Representational Models

Miller and Cohen (2001) put forth an important representational model of the role of prefrontal cortex in executive control. They proposed that the prefrontal cortex represents goals and the means to achieve them, thereby allowing for executive control in the face of distraction. Inflexible, automatic behaviors that are stereotyped reactions to specific stimuli are associated with other areas of the brain. According to Miller and Cohen, the prefrontal cortex comes into play when top-down processing is involved and internal representations must be used to select task-relevant, but weakly established or novel behaviors, in the face of competition from task-irrelevant, but stronger, more established responses. Miller and Cohen assumed that processing in the brain is competitive. Consequently, whenever multiple responses are possible and a weak task-relevant response is appropriate but needs to compete with stronger task-inappropriate responses, the prefrontal cortex biases or guides neural activity along specific pathways that lead to the appropriate response. The specific function of the prefrontal cortex is to generate and maintain representations of mean-ends relations. In short, they considered the prefrontal cortex as "active memory in the service of control" (Miller & Cohen, 2001, p. 173) that can sustain active representations over time to guide behavior even in the face of distraction. Moreover, based on Petrides's (1985) research suggesting that patients with frontal damage lose the ability to learn conditional associations, Miller and Cohen suggested that the prefrontal cortex represents contingencies between general abstract rules and responses rather than contingencies between particular cues and responses.

Miller and Cohen (2001) proposed a number of other minimal requirements for top-down control by the prefrontal cortex to be possible. For example, they suggested that representations subserved by the prefrontal cortex must be multimodal and integrative. The prefrontal cortex also must access and integrate internal and external information. Indeed, Miller and Cohen concluded that given its interconnectivity with other brain regions, the prefrontal cortex is not only particularly well suited at representing diverse sources and kinds of information, but it is also well suited for returning feedback to these other brain regions, allowing for learning to take place.

Late Adulthood Representational Models

Both documented changes in prefrontal cortex and decreased performance on EF tasks with advancing age have led some to propose the *frontal-lobe hypothesis* of late adult cognitive development (e.g., West, 1996). This hypothesis has been criticized, however, for its lack of specificity and because some have demonstrated that age-related variation on EF tasks disappears when lower cognitive processing abilities have been controlled (see Daniels et al., 2006, for a review). Recently, more specific models of late adult cognitive development involving EF have emerged. For example, Craik and Bialystok (2006; see also Bialystok & Craik, Chapter 7 of this volume) propose a representational model of cognition and executive control applicable across the life span. In their account, both representational and control processes contribute in an interactive way to the development of EF. Craik and Bialystok argue that representational processes influence cognition in terms of their content: Knowledge schemas are built from interactions with the environment. Control processes are the processes that operate on existing representations. However, both representational and control processes mutually influence each other; specific kinds of representations are limited by the control processes available to individuals to generate them, whereas control processes are influenced by existing knowledge structures. In their words, "control processes determine the construction of representations, and these representations later play a part in further controlled processing" (Craik & Bialystok, 2006, p. 132).

Changes to the representational system show the largest increase during childhood, growing less rapidly during adulthood and remaining relatively stable through late adulthood. Like other accounts of cognitive development (e.g., Gibson, 1969; Inhelder & Piaget, 1959/1964; Smith, 1984, 1989; Vygotsky, 1934/1986; Werner, 1948; Zelazo & Frye, 1997), Craik and Bialystok (2006) proposed that children's representational knowledge structures become increasingly hierarchical with age with the construction of more generalized representations. Thus, as children's representational abilities increase, their representations become more conceptual and less context dependent. In older adults, however, context once again becomes increasingly important for them to access more specific and detailed stored representations, although their more generalized conceptual representations remain relatively intact.

In contrast, internal control processes necessary for overriding prepotent, externally determined responses increase during childhood and early adulthood but decline thereafter. Control processes are intentional and conscious, and likely to be associated with working memory. Because of distinct developmental trajectories of representational and control processes, Craik and Bialystok (2006) argued that each influence EF at different points in development, with representational difficulties contributing more to EF processes in early childhood and control difficulties contributing more in late adulthood. Both processes, however, have at least some impact on EF abilities, but for different reasons. For instance, in children, knowledge-related difficulties that contribute to EF difficulties often arise from incomplete acquisition of relevant information, whereas in late adulthood, knowledge-related difficulties that contribute to EF difficulties often can stem from difficulties with accessing stored relevant information.

Componential Models

Several componential models of EF have been proposed across the life span. Although they differ in many respects, these models have in common that they stipulate a group of more or less correlated but distinct EF abilities. Some of these models have been developed based on findings that EF measures are typically only moderately correlated, suggesting that different yet related EF processes are implicated (e.g., Carlson, Mandell, & Williams, 2004; Carlson & Moses, 2001), whereas others have been proposed as a result of empirical investigations using exploratory or confirmatory factor analyses (e.g., Hughes, 1998; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Welsh et al., 1991; see Garon et al., 2008, for a review). Results from such studies have yielded sets of correlated factors suggesting that a number of distinguishable EF abilities exist. Moreover, some models (but not all) stipulate an overarching common underlying mechanism that relates the separate EF abilities. We present some examples of componential models proposed to account for EF at different points in the life span.

Childhood Componential Models

Diamond (2006b) proposed that there are only three EF processes—namely, inhibition, working memory, and cognitive flexibility—and argued that these processes become better coordinated with development because of maturation of the dorsolateral and ventrolateral prefrontal cortex. According to Diamond (2006b), the dramatic growth of the prefrontal cortex between 7.5 and 12 months of age leads to radical improvements in a variety of infant-appropriate EF tasks (e.g., delayed response task, A-not-B task, object retrieval task). In the second year of life, there is marked improvement in the ability to process physically and conceptually unconnected things (e.g., delayed nonmatching to sample task), which she associated with the growth of the inferior frontal junction. In older children, there is a strong relation between faster processing and EF ability, which Diamond linked to system-wide improvements to neural circuitry (increased myelinization) or to the fact that stronger prefrontal cortex provides better signals for diverse neural regions.

Borrowing from the adult framework that Miyake et al. (2000; described in the next section of this chapter) proposed, Garon et al. (2008) recently presented a new componential model of the development of EF during the preschool years. They suggested that EF consists of a set of common and separable EF components that are organized hierarchically. They proposed that EF processes exist to resolve conflict (cf. Diamond, 2006b; Munakata, 2001) between (1) different representations, (2) representations and prepotent responses, or (3) incompatible response sets. Drawing from Posner and Rothbart's (2007) work on attention, Garon et al. suggested that attention is the common underlying mechanism that influences all three core EF components (working memory, response control, and set shifting). Developments in attentional abilities are believed to underlie developments in EF across the preschool years. For example, early improvements in EF and goal-directed behavior in infancy are thought to occur as a result of an increased ability to focus attention on task-relevant information while ignoring task-irrelevant information. Based on Posner and Rothbart's theory, Garon et al. suggested that developmental changes in selective attention result from changes in two complementary attentional systems, an orienting system that emerges in infancy and allows children to orient to and shift attention between different external stimuli, and an anterior attention system that emerges later in the preschool years and allows children to select and enhance attention on the basis of internal representations. Changes in the preschool years are believed to result from an increase in the control of the anterior attentional system over the orienting one, which, in turn, allows children to stay in a state of focused attention for a longer amount of time (sustained attention) and flexibly shift the focus of their attention as a function of task goals. Infants first learn to shift attention between external stimuli, and later learn to shift attention between internal representations and external stimuli. Furthermore, in early development, focusing and shifting aspects of attentional processes are not fully integrated and actually compete with each other (Jones et al., 2003). However, with development, these two attentional processes become integrated, allowing for advances in EF.

Garon et al. (2008) delineated specific developmental changes for each of the three core EF abilities during the infancy and preschool periods. Young infants show improvements in simple working memory tasks in their first year of life, whereas they do not succeed on complex tasks until their second year. Garon et al. also differentiated between simple and complex response inhibition tasks in that they proposed that simple response inhibition tasks require only withholding or delaying a single prepotent or automatic response. In contrast, complex response inhibition tasks require responding according to a rule held in mind while inhibiting a prepotent response. Finally, they differentiated between simple and complex set-shifting tasks, referring to simpler ones as response-shifting tasks and to more complex ones as attention-shifting tasks. On the one hand, response-shifting tasks require forming an arbitrary stimulus–response set and then shifting to another arbitrary stimulus–response set. On the other hand, attention-shifting tasks also require learning one stimulus–response set and shifting to another, but these mappings involve two different aspects of the same stimuli. Moreover, attention-shifting tasks also require response shifting because some degree of response remapping must necessarily be involved for successful performance.

Adulthood Componential Models

Garon and colleagues (2008) constructed their developmental componential model of EF abilities in preschoolers drawing extensively from Miyake et al.'s (2000) findings regarding the unity and diversity of EF. Miyake et al. used confirmatory factor analysis and structural equation modeling to determine whether EFs can be fractionated into separate distinct functions in adults. They assessed young adults on several relatively simple but diverse tasks purported to assess the "updating function" of working memory, response inhibition, and set shifting. Using confirmatory factor analysis in which they assigned specific tasks to their purported functions, Miyake et al. tested four kinds of models: a single-factor model, separate models with two factors, a model with three independent factors, and a model with three factors that were allowed to correlate. The latter of these models best fit the data.

In addition, they assessed participants on more complex tasks (e.g., Wisconsin Card Sort Test, *Tower of Hanoi, Random Number Generation Task*) that have been used extensively in the literature and assumed to test specific EF abilities. The authors found that some of the tasks tended to load on specific EF processes. For example, the Wisconsin Card Sort Test loaded on the set-shifting factor, whereas the Tower of Hanoi and some of the response variables from the Random Number Generation Task loaded on the inhibition factor. Other response variables from the random number task loaded on the updating factor. Interestingly, dual-task performance—performing two independent tasks simultaneously—did not load on any EF factors, despite the assumption that dual-task performance might require set shifting given that participants need to shift continuously between two tasks. This finding suggests that EF-related set-shifting requirements are not involved when participants must coordinate and engage in two unrelated tasks simultaneously. Set shifting may be implicated only when individuals must switch between two incompatible representations of the same task; that is, when they must consider the same stimuli from different perspectives.

On the basis of their findings, Miyake et al. (2000) concluded that there is sufficient evidence of both unity and diversity of EF processes; that is, each of the EF components (updating, set shifting, and inhibition) appear to be separable, yet they are all interrelated, suggesting that although they share some degree of commonality, they likely do not reflect the same underlying mechanism. Miyake et al. speculated about potential ways in which these processes might relate with each other, but they did not commit themselves to one particular proposal. Moreover, their results suggest that even though individual differences in performance on complex tasks used to assess EF, such as the Wisconsin Card Sort Test, could result for any number of reasons, performance on these complex tasks at least loaded on relevant EF processes for young adults. Thus, at least for typical young adults, individual differences in performance on these complex EF tasks likely result from efficiency of specific EF processes. This interpretation, however, should not be generalized to other age groups or to clinical groups, because difficulties in any of these groups on these same tasks could arise for other reasons given the number of processes that need to be intact for successful performance on these tasks.

Other Models

Other models of EF that do not fall neatly into the representational versus componential model distinction exist. Many of these models, although they differ substantially, actually integrate aspects of both representational and componential models. We briefly highlight some of these models.

Childhood Other Models

Early developmental models of EF tended to emphasize a unitary inhibitory mechanism (e.g., Dempster, 1992; Harnishfeger & Bjorklund, 1993). For example, Dempster (1992) argued that improvements in inhibitory processes during cognitive development, and conversely, impairments in these same processes in late adult cognitive development, can be traced back to the growth and decline of inhibitory processes necessary to resist interference. Likewise, Harnishfeger and Bjorklund (1993; Bjorklund & Harnishfeger, 1990) proposed that inhibitory processes become more efficient over childhood in an "outward-in" direction, with inhibitory control initially arising in response to adult directions, then arising from children's own overt behavior (i.e., self-directed speech), and finally through covert self-direction. Consequently, the developing ability to keep inappropriate information out of working memory leads to vast improvements in cognitive development.

In contrast, Barkley (2001) took a functional view of EF, suggesting that executive acts serve to modify one's own behavior in the future. Specifically, EFs are considered to be classes of self-directed actions used to promote self-regulation; thus, all EFs require response inhibition. Furthermore, EFs have developed across the evolutionary time course; they began as overt behaviors but have become covert as humans have become more adept at self-regulation and have found it increasingly necessary to protect self-directed thoughts from social imitators. Barkley argued that EFs follow the same developmental progression in childhood, developing from overt to covert, although one cannot engage in overt and covert forms of EFs simultaneously.

From this perspective, Barkley (2001) proposed four EFs that form a stage-wise hierarchy such that an earlier EF is needed for a later EF: (1) nonverbal working memory (sensing to the self), (2) verbal working memory (speech to the self), (3) self-regulation of affect/motivational/arousal (emotion/motivation to the self), and (4) reconstitution (play to the self). Nonverbal working memory has both retrospective and prospective functions, and thus becomes the mental module for anticipating the future from the experienced past. It relies heavily on the privatization of visual and auditory events, and these representations form the basis of eventual symbolization. Finally, resensing one's past experiences presumably forms the basis of autonoetic awareness. Verbal working memory is characterized by the privatization of speech that allows for self-description, reflection, self-instruction, self-questioning, and problem solving. Self-regulation of affect/motivation/arousal arises from the existence of the first two EFs. Mentally represented events have associated somatic markers that are paired initially with publically observable behaviors (e.g., laughing out loud). This EF serves to privatize affect and arousal, resulting in covert forms of the paired behaviors, and thus becomes the basis for intrinsic motivation that initiates behavior. Reconstitution, in turn, is the internalization of play, which can be thought of as mental simulations of events. This allows for the internal generation and execution of novel actions without real-world consequences, and is essential for planning and problem solving.

Adulthood Other Models

Engle and Kane (2004; Kane & Engle, 2002) have recognized the importance of working memory capacity in predicting a wide array of psychological functions. From their perspective, individual differences in working memory capacity, typically measured using complex span tasks in the face of demanding secondary tasks, do not reflect storage limitations per se, but rather the executive control needed to maintain information in an active state. Compared with individuals with high working memory capacity ("high spans"), those with low working memory capacity ("low spans") have difficulty maintaining goals in active memory and resolving response competition. Unlike some models of EF that postulate that working memory is a subcomponent of EF, Engle and Kane take a different approach in postulating that executive control is a subfeature of working memory (Engle & Kane; Engle, Kane, & Tuholski, 1999; Kane, Conway, Hambrick, & Engle, 2007; see also Baddeley, 1986; Case, 1992, 1995; Gordon & Olson, 1998;

Olson, 1993; O'Reilly, Braver, & Cohen, 1999; Pascual-Leone, 1970; and Roberts & Pennington, 1996, for other models that give working memory a pivotal role in EF or cognition more generally). In Kane et al.'s (2007) model, short-term memory consists of long-term memory traces that are activated above threshold. Maintaining these traces in an active state requires grouping/chunking, coding, and/or rehearsal strategies, which may be within or outside of consciousness. For example, maintaining the rules of a Stroop task (i.e., name the color of the font but do not read the word) may be easy and relatively automatic for high-span adults, but challenging and resource demanding for low-span children. The central executive is best described by endogenously controlled attention and is responsible for regulating the skills needed to keep memory traces active, retrieve information from outside of conscious focus, and block goal-irrelevant representations or inappropriate responses elicited by the environment. The extent of executive control engagement is determined by the degree of conflict presented in the context, and further modulated by familiarity and practice with particular skills.

Late Adulthood Other Models

Models of EF in older adults typically account for age-related decreases in cognitive abilities, including increased susceptibility to proactive and retroactive interference. Salthouse (1996) postulated that declines in processing speed accounts for a domain-general decrement in cognitive performance in late adult populations. He further proposed that the relation between speed and cognition in older adults arises from limited time because of cognitive processes that are executed too slowly and from deficits in high-level processing because of a reduction in the amount of available information. Verhaeghen et al. (1997) also argued that the ability to coordinate complex components into a reliable sequence is a process that is separable from processing speed (see also Chalfonte & Johnson, 1996; Craik & Byrd, 1982).

Hasher and Zacks (1988) further implicate inhibitory processing failures in working memory as a major determinant in the reduced cognitive functioning of older adults. In their view, deficiencies in inhibition are responsible for hindering the retrieval of critical information, usually because inappropriate information (e.g., previously correct information, distracting stimuli, current concerns of the subject) is not inhibited effectively and persists in working memory for a prolonged period. One consequence of weakened inhibition is that older adults have more difficulty giving up previously held inferences in light of new information. Furthermore, as the coordination of complex components requires keeping representations encapsulated, inhibition failures make this difficult, leading to "cross talk" among simultaneously active representations. Notably, well-educated older adults with high verbal memory are often protected from the considerable age-related decline in cognitive functioning, suggesting that experience and efficient strategy implementation on cognitive tasks are important in mitigating age-related decline (Hasher & Zacks).

Braver and West (2008) speak directly to the role of EF in cognitive decline (but see Salthouse, Atkinson, & Berish, 2003, for an alternative view) in their goal-maintenance account of late adult cognitive development, suggesting that active maintenance of the goal is a primary indicator of success on cognitive tasks (Kane & Engle, 2003; Marcovitch, Boseovski, & Knapp, 2007). They further postulate that successful goal maintenance requires inhibition of inappropriate goals. Support for this hypothesis comes from a number of sources, including research on prospective memory (i.e., remembering to do something in the future). For example, Smith and Bayen (2006) reported that older adults have more difficulty with prospective memory tasks. One path to efficient prospective memory is through active goal maintenance, which may be difficult for older adults who have trouble maintaining intentions across delays as short as 5 seconds (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000; McDaniel, Einstein, Stout, & Morgan, 2003). Similarly, Braver, Gray, and Burgess (2007) have argued for a distinction between proactive and reactive cognitive control. Simply put, proactive control occurs in anticipation of an event, whereas reactive control is stimulus driven. According to this model, older adults show reductions in their usage of proactive control.

AN INTEGRATED DEVELOPMENTAL MODEL OF EXECUTIVE FUNCTION

We argue that a developmental model encompassing key features from the described existing models provides the best account for EF across the life span. This model includes both componential and representational features. In brief, like Engle and Kane (2004) and others (e.g., Case, 1992, 1995; Gordon & Olson, 1998; Olson, 1993; Pascual-Leone, 1970), we propose that variability in working memory best accounts for variability in EF. In other words, the development of working memory abilities are most likely instrumental in the emergence of the two forms of executive control processes (viz. cognitive and response control). Specifically, in this model, working memory is understood as the representational vehicle that permits relevant information to be kept in mind, information that is critical for one to be able to exert control over one's thoughts and behaviors, permitting cognitive flexibility on the one hand and response control on the other. In this respect, this is a representational model. However, the model is also componential because it distinguishes between the three core EF processes (working memory, cognitive flexibility, and response control). Whereas many componential models often (implicitly, at least) describe working memory as its own independent EF process (e.g., Diamond, 2006b; Garon et al., 2008; Miyake et al., 2000), we, like Engle and Kane (2004), view working memory as a contributor to the other two processes. Figure 13.3 depicts the proposed links between the three core EF processes. Thus, this model is representational in its assertion that how information is represented affects executive control. However, unlike some representational models (e.g., Bialystok & Craik, Chapter 7 of this volume; Craik & Bialystok, 2006; Miller & Cohen, 2001), two forms of executive control (viz. cognitive vs. response control) are differentiated.

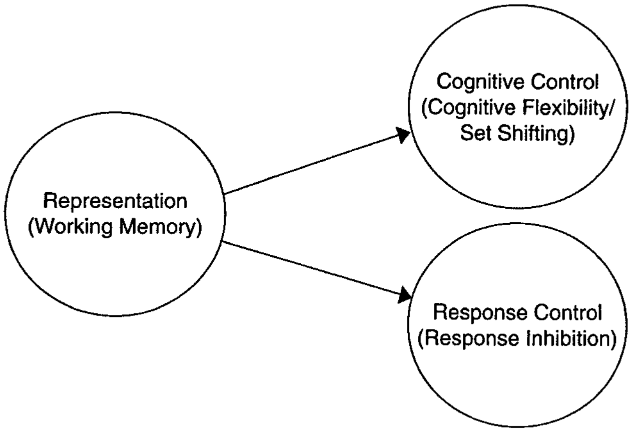

Figure 13.3 An integrated model suggesting a causal link between specific representational capabilities and specific forms of control.

This section describes key characteristics of working memory representations that allow one to exert control over one's own thoughts and behavior. These characteristics are not new; in fact, they are drawn directly from existing theories described in the previous sections—although no existing theory proposes *all* of these characteristics into a single model. For example, Miller and Cohen (2001) emphasize goal representation and representations that are resistant to distractions, but they do not consider development, which we view as essential in any theory of EF. As another example, Zelazo et al. (2003) place great emphasis on the influence of representational changes across development on EF processes at different ages, but they do not fully incorporate the concept of working memory processes within their conceptualization of EF (see also Zelazo et al., 1997).

Working memory has received considerable attention in recent decades, particularly as a result of the seminal work by Baddeley and Hitch (1974; see Baddeley, 1986, 2003; and Hitch, 2006, for reviews). Baddeley (1986) defined working memory as "a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as comprehension, learning and reasoning" (pp. 33–34). He argued that any model of working memory must distinguish and incorporate at least two components: On the one hand, working memory requires a storage component so that information can be maintained online; on the other hand, it must include a processing component that can manipulate this stored information. Specifically, Baddeley (1986) proposed a working memory model that includes two storage subsystems, namely, an articulatory loop and a visuospatial scratch pad, which differ in terms of the type of information that each is able to hold (i.e., linguistic vs. visuospatial information, respectively), and a supervisory controlling subsystem, referred to as the central executive, which processes information stored in the two storage subsystems.

This initial notion of working memory has evolved and several other models have emerged (see Miyake & Shah, 1999; and Demetriou, Mouyi, & Spanoudis, Chapter 10 of this volume, for reviews of major theoretical approaches). Researchers generally agree about the existence of two types of working memory tasks (e.g., Garon et al., 2008; Hitch, 2006); tasks that place only storage demands on working memory are generally considered simple working memory tasks or short-term memory tasks, whereas those that require participants to store and process information simultaneously are labeled complex working memory tasks. Existing research on the development of working memory across the life span has also tended to focus on developmental changes in working memory *capacity* and *function*. Although capacity and function are important, the particular contents of working memory are also critical for effective executive control (cf. Bialystok & Craik, this volume; Craik & Bialystok, 2006; Zelazo et al., 2003).

Drawing from existing theories, the integrated model proposes that there are several features of working memory that may be essential for successful EF (see Table 13.1). The first of these features is the maintenance of *task goals* (cf. Engle & Kane, 2004; Miller & Cohen, 2001). Second, early working memory representations, especially goal representations, must be *resistant to interference* from task-irrelevant stimulation (cf. Garon et al., 2008; Hasher & Zacks, 1988; Marcovitch et al., 2007; Miller & Cohen). A failure to represent the goal during problem solving in the face of distractions would lead to EF failures. Moreover, *early working memory* representations are likely to be constructed using bottom-up processes from perceptual-motor information (as opposed to internally generated ones) but maintained internally in the form of *sensorimotor representations.* From the perspective of this integrated model, early EF abilities are also likely to develop on the basis of improvements in an infant's basic ability to *maintain information.* As a result, these early working memory abilities can be tapped by simple working memory tasks because maintaining information in working memory suffices for early executive control (cf. Garon et al.).

Table 13.1 Proposed Characteristics of Working Memory Representations

1. Early Executive Control Depends on Storage of Representational Content
   a. Goal representation—actively maintains goal in mind
   b. Representations resistant to distraction
   c. Sensorimotor-derived representations
2. Advanced Executive Control Depends on Storage and Processing of Representational Content (monitoring, manipulating, and/or updating)
   d. Verbally mediated, language-based representations
   e. Internally generated, abstract conceptual representations

Although maintaining representations in working memory is critical at all levels of EF, processing the representational content held in mind by monitoring, manipulating, or updating it becomes increasingly important for the emergence of advanced executive control. With new EF processing requirements come novel constraints on the specific form and content of working memory representations. Specifically, based on early research by Luria (1959a, 1961) and Vygotsky (1929), it is hypothesized that advanced executive control requires complex working memory representations that are *linguistic* in nature. Further, the *abstract and conceptual* (i.e., symbolic as distinct from sensorimotor) nature of these representations provides the base for new levels of executive control to emerge during the preschool years (cf. Blaye & Jacques, 2009; Carlson & Beck, 2009; Jacques & Zelazo, 2005a; Jacques et al., 2010; Kharitonova, Chien, Colunga, & Munakata, 2009; Luria, 1959a; Zelazo & Frye, 1997). Abstract linguistic representations are necessarily *internally generated* using top-down processing rather than generated from available sensorimotor information. Thus, approaching a task relying on (verbal) representations that are also internally generated allows children greater control over their behavior than relying on externally derived representations. That is, because abstract representations are further separated from perceptual experience, they are more robust and easier to manipulate (cf. Carlson & Beck, 2009; Carlson, Davis, & Leach, 2005; Jacques & Zelazo, 2005a).

EMPIRICAL EVIDENCE FOR REPRESENTATIONAL DEVELOPMENT IN WORKING MEMORY AND EXECUTIVE CONTROL PROCESSES

This section reviews research that provides support for the claim that developmental changes in the representational features of working memory are associated with the development of cognitive flexibility and response control; the review is limited to EF research that has identified links between these processes. In particular, it discusses research across the life span that is relevant to the model features of working memory described in the previous section. Much of the research reported in this section involves child research because less research has been documented with younger and older adults on the specific features identified in this model. When possible, however, this section reviews relevant adult research.

Early Working Memory Representations

With respect to development, the complexity of information held in working memory likely depends on the actual or functional limits of working memory capacity. Thus, the structure and the content of working memory are vital developmental considerations. As a result, the number and complexity of representations that one is able to hold in mind both increase with development. In fact, the complexity of the representations that one is capable of holding in mind may be limited, in part, by the number of items that one can represent (e.g., Case, 1992, 1995; Case et al., 1982; Pascual-Leone, 1970). For example, representing a specific relation between two objects requires not only representing this relation but representing each object as well, thus requiring a minimum of three units of information held in working memory (cf. Guttentag & Lange, 1994; Halford, Wilson, & Phillips, 1998). Thus, if only two units of working memory capacity are available, only two objects could be represented at any one time, leaving no functional space available for representing a relation between them.

For instance, as described earlier, Diamond (Diamond et al., 1999; see Diamond, 2006a, for a review) reported that infants do better at a much earlier age on EF tasks, such as the object retrieval task or the delayed nonmatching-to-sample task, if objects are physically connected to each other than if objects are spatially distinct. Diamond (2006a) argued that the physical connectedness between objects helps infants see their conceptual connectedness earlier, allowing them to deduce abstract rules about their relations. Instead, perhaps infants do better earlier when objects are physically connected because objects and their relation can be represented in working memory using fewer units of information than if they are separated, thereby alleviating constraints on working memory representations that might make it difficult for infants to use these representations to govern their behavior.

Hence, because of limitations in functional working memory capacity, infants are likely to succeed first on EF tasks that require little functional working memory space. The simplest EF tasks are ones in which infants need only represent a goal over a delay in the face of distraction.

Goal Representation and Goal Neglect

Goal representation is a necessary feature of problem solving and, thus, a defining feature of EF tasks. Goal representation may be defined as the ability to maintain the goal in mind and act in a manner consistent with achieving this goal despite distractions. There is clear evidence that children can accomplish this by 2.5 years of age.

For example, Bullock and Lütkenhaus (1988) directly examined goal representation by exploring whether 15- to 35-month-old children could maintain an externally defined goal in mind and act on the basis of that goal. In a block-building task, children were shown how to build a figure (e.g., a house) with three blocks (i.e., the standard). They were then asked to reproduce the same figure as the experimenter. Children were given replicas of the three blocks used by the experimenter in addition to a fourth, irrelevant block to determine whether they could focus on producing the specific goal (i.e., the house) and stop once the goal had been reached despite the presence of a distracting object designed to lead them to focus on the activity of block building itself instead of the goal. This study found that the majority of the youngest toddlers did not act in an appropriate goal-oriented manner. That is, younger children showed no evidence of using the standard in their manipulation of the task materials and instead manipulated the materials in unsystematic ways (e.g., banging blocks together). Although 26-month-olds were more outcome oriented in that they tried to reproduce figures on the basis of the standard, they were driven by the task materials, building the figure incorrectly and or failing to stop when required. Reproductions of the standard were most consistent for 32-month-olds. Although it is not clear why the younger children failed to reproduce the figure (e.g., they may have failed to understand the task or been particularly susceptible to the presence of a distracting block), it is clear that by 32 months, children can hold a goal in mind and act on the basis of that goal despite distractions. Of particular relevance, in following up this work, Silverman and Ippolito (1997) found that goal-directedness is associated with inhibitory control abilities as assessed using simple delay tasks. These findings are consistent with the idea that goal representation is an important feature of executive control.

There are many reasons why children and adults may fail to solve a particular problem as a result of goal-representation difficulties. On the one hand, they may hold the wrong goal in mind or no particular goal at all, perhaps as a result of not understanding task instructions. For example, Kaler and Kopp (1990) demonstrated that language comprehension limitations are related to young children's ability to control their behavior. The authors found that infants who failed to comply with requests generally did not comprehend nouns or verbs used in these requests when comprehension for these words was assessed independently. Thus, a simple failure to represent the correct goal in mind may account for some EF difficulties. This point is similar to one raised several times in this chapter: Poor performance on EF tasks can occur for several reasons and, therefore, can be difficult to interpret.

On the other hand, there may be situations in which children and adults demonstrate that they can represent the correct goal, but for one reason or another, fail to use this representation when attempting to solve the problem. This failure to behave appropriately in relation to a particular goal despite demonstrating knowledge of the appropriate actions, when this failure is attributable to an inability to maintain the goal in active memory, is referred to as *goal neglect* (Daniels et al., 2006; Duncan, Emslie, Willams, Johnson, &

Freer, 1996; Kane & Engle, 2003; Marcovitch et al., 2007). For example, *failure to maintain set* errors on the Wisconsin Card Sorting Test, errors that occur after a number of correct responses to a particular category, likely reflect goal-neglect errors because participants fail to respond according to the current sorting category despite having demonstrated on previous trials that they can sort by that category.

Other examples of goal neglect are common in the developmental literature, although not reported as such. For instance, despite looking at the correct location, infants around 1 year of age still perseverate on the A-not-B task when required to reach for the hidden object manually (Hofstadter & Reznick, 1996). Similar dissociations between looking and reaching have been noted at 2 years of age on more complex versions of the A-not-B task (Zelazo, Reznick, & Spinazzola, 1998). Moreover, infants who fail the A-not-B task act surprised when they see the object at the wrong location (Ahmed & Ruffman, 1998). Together, these findings indicate that, although young children can fail the A-not-B task (or one of its variants), they still demonstrate some understanding of where the object should be. By 3 years of age, children also exhibit knowledge dissociations on the Dimensional Change Card Sort, in that they are able to point to the correct target despite sorting cards perseveratively (Zelazo, Frye, & Rapus, 1996), and on false-belief tasks, in that they look at the correct location despite reporting the wrong location (Clements & Perner, 1994). Although indirect, all of these dissociations suggest that failures on EF tasks might result from goal neglect because children show some evidence that they know what to do but fail to use that knowledge when attempting to solve these tasks.

More recently, several studies have investigated goal neglect directly in children and adults. For example, based on a goal-neglect task developed by Duncan et al.'s (1996) adult task, Towse, Lewis, and Knowles (2007) presented 4-year-old children with pairs of food stimuli. On some trials, a cue was presented (e.g., an arrow) that prompted children to attend to and name items on a particular side of a computer screen for a number of trials (e.g., a right-pointing arrow indicated naming items on the right-hand side, whereas a left-pointing arrow indicated naming items on the left-hand side). After a series of trials, another type of cue was then presented (e.g., a colored box), which either required that children attend to the same side or shift attention to the other side (e.g., a red box indicated naming items on the left-hand side, whereas a blue box indicated naming items on the right-hand side). Despite demonstrating knowledge of the appropriate cue-direction contingencies, children often persisted in naming items on the same side even after a new cue prompted them to shift attention to the other side. Towse et al. (2007) argued that this failure to shift attention provides evidence of goal neglect because children failed to update their goal based on the appearance of the cue and incorrectly relied on the old goal. In a very real sense, proficiency in task switching appears to require the ability to remain alert to cues that require a change in goal representations.

Recent research by Marcovitch and colleagues (2007) suggests that active and sustained representation of the goal is important for successful performance on EF tasks, and that conditions that reduce children's tendency to maintain the goal actively in mind may make them prone to err on EF tasks. In Marcovitch et al.'s goal-neglect version of the Dimensional Change Card Sort, devised on the basis of a modified Stroop task used with adults (Kane & Engle, 2003), 4- and 5-year-old children were given two types of test stimuli: standard conflict test cards, which matched each target on a different dimension, and redundant test cards, which were identical to the targets and, therefore, matched one of them on both dimensions. It is necessary to attend to the rules provided to sort conflict cards correctly because successful performance is underdetermined by the stimuli. This is not the case for sorting redundant cards, however, because sorting by either dimension would lead to a correct response. Thus, for redundant cards, active and sustained representation of the goal itself (e.g., "sort by color") is not necessary for successful performance. Marcovitch et al. found that in a mostly redundant condition in which 80% of the cards were redundant and 20% were conflict, 4- and 5-year-old children made relatively large numbers of perseverative errors in the postswitch phase compared with children in a mostly conflict condition in which 80% of the cards were conflict. These findings suggest that despite knowing what to do as demonstrated by their ability to sort correctly in the postswitch of the mostly conflict condition, 4- and 5-year-olds can perseverate on this task if they are placed in a context in which they are less inclined to maintain the goal in mind. Of particular interest, recent work has tied success on this goal-neglect version of the Dimensional Change Card Sort with individual differences in working memory capacity in 4- to 6-year-olds (Marcovitch, Boseovski, Knapp, & Kane, in press), consistent with the idea that working memory development, goal representation, and executive control abilities are related.

Representations Resistant to Distractions

It was proposed earlier that success on simple executive control tasks requires maintaining a goal representation in mind in the face of possible distraction (cf. Garon et al., 2008). However, few studies have directly examined the specific effects of the presence of distractions on EF performance. In one early study, Luria (1959a) examined the role of perceptual and motor distractions in relation to infants' ability to control behaviors that they could control in the absence of distractions. For instance, Luria found that, although 12- to 14-month-olds were able to obey simple directives (e.g., "Give me the horse."), they failed to do so when these same directives conflicted with their prepotent response tendencies. Specifically, when infants were presented with a toy fish and a toy horse, and were asked to give the experimenter one of the two toys (e.g., "Give me the horse."), they succeeded on several successive trials. However, when then asked to switch and give the alternate toy, they perseverated and handed the experimenter the original toy. Fourteen- to 16-month-olds had difficulty obeying similar directives when these conflicted with their current ongoing motor responses. For example, if told to put a ring on a stick while in the process of removing another ring, they failed to suppress the ongoing action (Luria, 1959a). Similarly, their ability to obey directives was easily disrupted by the presence of perceptually salient stimuli. For instance, when asked to retrieve a toy placed farther away from their body than another toy, infants tended to grasp the more proximal and, presumably, perceptually more salient toy. It was not until the age of 16 to 18 months that infants succeeded in guiding their behavior according to directives, without being susceptible to either perceptual or motor conflicts. These findings support the contention that distractions play a role in failures to maintain goal representations in this age range, and that in part what develops in the late infancy period is the ability to maintain representations while resisting distractions.

Representations Constructed from Sensorimotor Information

Luria's (1959a) work also provides evidence supporting the idea that early success on EF tasks is related to sensorimotor rather than abstract representations. Luria found that infants between the ages of 18 and 24 months were unable to follow verbal directives if these directives required searching for hidden (as opposed to visible) objects (e.g., "The coin is under the cup. Find the coin!"). Admittedly, poor performance on Luria's verbal search task could result from a simple lack of understanding of the directives. However, this latter interpretation is unlikely to suffice because Luria also found on a verbal analogue to the A-not-B search task that 20- to 24-month-olds could find a hidden object on the basis of verbal directives alone at a first location, but if the coin was hidden at a second location, they searched perseveratively at the previous hiding location. The finding that 2-year-olds could search at the first location on the basis of verbal directives alone suggests that they understood instructions. Their failure to search correctly at the second location, however, suggests that they failed to use verbal information to overcome their conflicting motor responses.

As discussed earlier, results from numerous studies clearly indicate that by 2 years of age, infants succeed on the conventional version of the A-not-B task. That is, they have no difficulty searching for hidden objects at different locations if provided with perceptual information from which they can generate their goal representation (i.e., directly observing the object being hidden). These findings suggest that they fail this verbal analogue of A-not-B task because they have to *infer* the object's location from verbal information alone (see also Sophian & Wellman, 1983). These findings support the notion that in the first 2 years, young children can exert control over their behavior using sensorimotor working memory representations before they can exert the same sort of control using abstract verbal representations. Obviously, the supportive evidence for this interpretation is still weak: Luria's results need to be replicated and extended to other paradigms. However, Luria's work is at least consistent with the idea that infants and young children initially succeed on simple EF tasks that require sensorimotor representations.

Advanced Working Memory Representations

Whereas sensorimotor working memory representations may suffice for success on early EF tasks, abstract, symbolic, linguistic representations are necessary prerequisites for the emergence of advanced EF abilities in the late preschool period (cf. Blaye & Jacques, 2009; Carlson & Beck, 2009; Jacques & Zelazo, 2005b; Jacques et al., 2010; Kharitonova et al., 2009; Luria, 1959a, 1961; Vygotsky, 1934/1986; Zelazo & Frye, 1997). Young children do not recode visual input into verbal representations in working memory spontaneously until the end of the preschool years. For example, unlike older children and adults, preschoolers are less likely to show phonological effects that are typically associated with verbal recoding on nonverbal working memory tasks (Gathercole, Pickering, Ambridge, & Wearing, 2004;

see Gathercole, 1998; Hitch, 2006, for reviews). By 6 years of age, however, children and adults do recode visuospatial information verbally in working memory, even when it is a detriment to do so. For example, adults who are prevented from verbally recoding ambiguous figures are better at identifying both images contained in the ambiguous figures (Brandimonte & Gerbino, 1993).

Although children in the 3- to 6-year-old range may not spontaneously recode visuospatial information verbally, if prompted to do by the introduction of labels, they demonstrate performance patterns typically associated with older children on cognitive tasks, including EF tasks (e.g., Jacques et al., 2010; Kendler & Kendler, 1961; Luria, 1959a). Thus, children between 3 and 6 years of age acquire the basic competence necessary for visual-verbal recoding, even though this competence may not always be apparent in their overt performance. The next section reviews research that demonstrates that language and labeling manipulations are closely associated with enhanced performance on measures of both cognitive flexibility and response control.

Verbally Mediated, Language-Based Representations

Whereas infants and young children gain control over their behavior through sensorimotor-derived representations, language and verbal mediation come to play an increasingly important role in advanced EF abilities as children develop (Luria, 1959a; Vygotsky, 1978; Zelazo, 1999). Deák (2003) and Jacques and Zelazo (2005b) have reviewed research that explores this topic and have presented evidence that language manipulations conducted with labels impact performance on many measures of cognitive flexibility and response control, including the Dimensional Change Card Sort, the Flexible Item Selection Task, and the go/no-go task. More important, the impact of labels appears to change between 3 and 4 years of age. Luria (1959a) attributed the change in the quality of label effects in this age range to the manner in which children use labels. He argued that younger 3-year-olds use *impulsive* aspects of labels to influence their behavior. That is, they use labels as some sort of auditory cue to act. Older preschoolers, in contrast, begin to use *semantics,* or the meaning of specific labels, to guide their behavior. That is, whereas young 3-year-olds can accompany motor responses on a go/no-go task with overt verbal responses (e.g., "press") that require them to act (i.e., pressing a ball), they cannot use overt verbal responses to inhibit their motor action (e.g., "don't press"). In the former case, the physical aspect of the verbal response (i.e., producing a verbal response) is congruent with the manual response required (i.e., producing a motor response). However, in the latter case, the physical aspect of the verbal response (i.e., producing a verbal response) is incongruent with the manual response (i.e., inhibiting a motor response), thereby creating a conflict between the impulsive (excitatory in this case) and semantic (inhibitory in this case) aspects of the verbal response. It is not until children are 4-years-old that they appear to use the actual meaning of the verbal responses to guide their motor responding (Luria, 1959a; see Jacques & Zelazo, 2005b, for an extended discussion).

Early research in the learning literature provided some correlational and experimental support for a link between language development and the development of flexible thinking in preschool children (e.g., Bruner & Kenney, 1966; Kendler & Kendler, 1961; Kuenne, 1946). For example, Kuenne found that preschool children who could articulate exactly how they solved transposition problems using appropriate relational terms such as "smaller" versus "bigger" succeeded on complex transposition problems, whereas children who could not verbalize their solutions solved only simpler transposition problems—problems that even nonhuman species can solve. Transposition problems require cognitive flexibility because children must select stimuli on the basis of their simultaneous relation with at least two other items. In a similar vein, Kendler and Kendler and others (see Esposito, 1975, for a review) found that introducing relevant labels experimentally allowed preschoolers to succeed on discrimination-shift learning paradigms, which also require cognitive flexibility (see Jacques & Zelazo, 2005b, for further discussion).

More recently, a body of research has emerged indicating that language abilities predict theory-of-mind development concurrently and longitudinally (see Astington & Baird, 2005; Milligan, Astington, & Dack, 2007). Although investigators disagree as to how language might be implicated in theory of mind development, one possibility is that language abilities influence the cognitive flexibility requirements of some theory-of-mind tasks, such as the false-belief task, rather than (or in addition to) affecting mental-state understanding per se (see Jacques & Zelazo, 2005a).

Several experimental studies have been conducted that manipulate labels with the Dimensional Change Card Sort (Kirkham, Cruess, & Diamond, 2003; McKay & Jacques, 2009; Müller, Zelazo, Lurye, & Liebermann, 2008; Towse, Redbond, Houston-Price, & Cook, 2000; Yerys & Munakata, 2006), but the results of these experiments have been mixed. For example, Kirkham et al. (2003) found that most 3-year-olds who were asked to label test cards by the relevant dimension in both the preswitch and the postswitch phases succeeded on the postswitch phase. However, in several studies, Müller et al. (2008) failed to replicate these findings. Like Kirkham et al. (2003), Towse et al. (2000) also found that children who managed to label correctly in the postswitch phase also tended to sort correctly, however, unlike Kirkham et al. (2003), Towse and colleagues (2000) found that children who labeled correctly represented only a minority of 3-year-olds. The majority of 3-year-olds did not label appropriately when asked about the postswitch dimension.

Jacques and Zelazo (2005b) suggested that labeling manipulations may be unreliable with deductive tasks (i.e., tasks in which children are explicitly told what to do) because the experimenter already provides labels for the relevant information when giving task instructions to children. As a result, labeling manipulations on deductive tasks often involve having a group of children who are exposed to their own and the experimenter's labels, and another group of children who are exposed only to the experimenter's labels (e.g., Kirkham et al., 2003). The comparison between conditions is not about the presence or absence of labels, but rather about being exposed to two kinds of labels versus one. In other words, in deductive tasks, it is difficult to include a group of children who are not exposed to relevant labels at all (but see McKay & Jacques, 2009; Yerys & Munakata, 2003). Consequently, any conclusions drawn from such studies are unclear because potential differences could result from additive effects of receiving a second label or from interactive effects of receiving two different kinds of labels.

As described earlier, the amount of explicitly labeled relevant information by the experimenter varies more in inductive tasks (i.e., tasks in which children must infer what they need to do). In studies in which labeling effects have been reported with inductive tasks, the experimenter (or children) sometimes labeled relevant aspects of the stimuli and sometimes did not. Although the influence of labels on the Dimensional Change Card Sort has been inconsistent, labeling manipulations using inductive measures of cognitive flexibility have been reported more consistently (e.g., the Flexible Item Selection Task, Jacques et al., 2010; the Flexible Induction of Meaning task, Deák, 2000; the discrimination-shift learning paradigm, Kendler & Kendler, 1961; a spatial relational mapping task, Loewenstein & Gentner, 2005).

For example, Jacques et al. (2010) investigated whether attribute (e.g., "red") and dimensional (e.g., "color") labels are associated with developmental changes in cognitive flexibility. In three studies using the Flexible Item Selection Task, they found that when 4-year-olds were asked to label (or the experimenter labeled) relevant dimensions on their first selection, their performance significantly improved on their second selection. In contrast, 3- and 5-year-olds did not improve in the label condition, likely as a result of floor and ceiling effects, respectively.

The finding that labels on the first selection related to better performance on the second selection is particularly remarkable because it suggests that labels on this task did not affect performance because of simple attention-directing properties. That is, several authors have argued that labeling effects on different tasks occur only because they direct children's attention toward important information about stimuli, helping them both to notice relevant information and to disregard irrelevant information (cf. Gibson, 1969; House, 1989; Kirkham et al., 2003; Murray & Lee, 1977). On this account, labels only have general, attention-directing properties, without promoting changes in children's representation or understanding of the task at hand, or in the cognitive processes that they use to solve the task. If labels acted only by directing children's attention to the relevant dimension on the Flexible Item Selection Task, then it is unlikely that labeling on *Selection 1* could influence *Selection 2* performance. In fact, if only attention-directing properties of labels were operating, then labeling on Selection 1 should have directed children's attention to the relevant dimension on Selection 1, making it even more difficult for them to identify the second dimension.

Instead, Jacques et al. (2010) suggested that labels help children access underlying conceptual knowledge about the stimuli rather than approaching the task at a perceptual level. In support of this interpretation, they found that 5-year-olds were more likely to label stimuli spontaneously than were 3- or 4-year-olds. Even though 4-year-olds were no more likely to label items spontaneously than 3-year-olds, 4-year-olds (but not 3-year-olds) were as likely as 5-year-olds to identify attributes correctly when asked to identify them (e.g., "What color are these pictures?"). In other words, despite not labeling spontaneously, 4-year-olds had well-organized dimensional knowledge. When explicitly provided with or asked to provide relevant labels, 4-year-olds performed better on Selection 2. Jacques et al. suggested that cognitive flexibility is a consequence of having and using underlying conceptual representations of dimensions. Three-year-olds did not benefit from labels because they did not have the underlying conceptual knowledge.

Jacques et al. (2010) proposed that labels help performance on the Flexible Item Selection Task for at least two reasons: labels provide a means of identifying specific dimensions via their members and a means of using the abstract representations themselves. First, because labels convey meaning about specific exemplars, identifying exemplars using distinct labels can help to accentuate the explicit contrastive relations that exist between exemplars of the same dimension (e.g., *red* vs. *blue* items). Second, labels provide useful symbolic tags for representing higher order dimensions (e.g., color), which, by definition, are not grounded in concrete representations (Nelson, 1988). Together, both of these aspects of labels help symbol users to go beyond perceptually given information. Jacques et al.'s approach shares some similarities with Gentner's (2003) structure-mapping approach, which also assigns an important role for abstraction and labeling.

Labeling has also been shown to relate to adults' cognitive flexibility across several tasks, for both younger (e.g., Glucksberg & Weisberg, 1966) and older adults (Kray et al., 2004). For instance, using Duncker's (1945) candle problem—considered a classic measure of cognitive flexibility—Glucksberg and Weisberg (1966) manipulated written labels to determine whether adults could solve the task more rapidly if relevant information was identified explicitly. Adults were presented with a candle, matches, and a box containing tacks. They were asked to affix the candle vertically against a wall, light it, and ensure that wax did not drip on the table or floor. Hence, to succeed, participants had to empty the box and affix it on its side against the wall with a tack before placing the candle on the box and lighting it. Adults often fail to solve the problem because they fail to use the box as a platform for the candle. Their failure to use the box is believed to result from their tendency to fixate on the box's current function (as a container), failing to consider that it could serve another function (as a platform). However, Glucksberg and Weisberg found that adults who were shown a relevant written label for the box found the correct solution more rapidly and demonstrated less *functional fixedness* than adults who were not shown this written label.

Kray and colleagues (2004) recently examined the role of labeling on a task switching paradigm in 9-, 21-, and 65-year-olds. Participants were presented with gray and colored pictures of animals and fruit. For one task, participants had to decide whether a picture was an animal or a fruit. For the other task, participants had to decide whether a picture was gray or colored. The instructional words "OBJECT" or "COLOR" preceded each target picture, informing participants of which task they were expected to do. To assess effects of verbal prompts, a task-compatible, task-incompatible, and task-irrelevant word (e.g., "gray"/"colored," "animal"/"fruit," "sand"/"round," respectively, for the Color task) appeared between the instructional word and the target picture. Participants were asked to read the word before making a decision about the target picture. Two control conditions (one including an intervening motor task and one including no intervening task between the instructional word and the target picture) were also included to assess the overall influence of performing a verbal task on performance. In single-task blocks, participants performed only one or the other task within each block, whereas in mixed-task blocks, they had to switch between tasks.

Kray et al. (2004) found an inverted-U–shaped pattern of developmental change in the cost to participants in selecting between task sets; specifically, young adults outperformed children and older adults. Moreover, only children benefitted from task-relevant verbal prompts relative to task-irrelevant prompts, and only older adults showed interference from task-incompatible prompts relative to task-irrelevant prompts. The finding that children benefitted from labeling task-relevant information is consistent with other studies noted earlier of labeling-related improvements in children. The finding that younger and older adults did not benefit substantially from task-relevant prompts compared with task-irrelevant prompts suggests that they may have spontaneously invoked their own task-relevant prompts. However, the finding that older adults found it difficult to ignore task-incompatible verbal prompts is consistent with the idea that older adults experience more difficulty in keeping distracting information out of working memory (cf. Hasher & Zacks, 1988). The researchers concluded that inner speech plays a central role in developmental changes in EF across the life span, but it may do so in different ways for different age groups.

Several investigations have assessed the relation between labeling and cognitive flexibility in adults by using a dual-task technique in which participants perform a primary task requiring cognitive flexibility and a secondary task that may or may not require verbal processing. The presence of a secondary task is presumed to limit relevant cognitive processes available for the primary task. Thus, if participants selectively do worse on the primary task when required to perform a secondary task that requires verbal processes than when it requires nonverbal processes, then this is taken as evidence that language is important for successful performance on the primary task. Using a dual-task approach, Jacques et al. (2010) gave adults a modified version of the Flexible Item Selection Task while doing a verbal secondary task, a nonverbal secondary task, or no secondary task. They found that participants' performance on their second selections was significantly worse when they simultaneously did a verbal secondary task than in the other two conditions, suggesting that language may be important for flexible thinking in adults. Baddeley et al. (2001; see also Emerson & Miyake, 2003; Goschke, 2000; Miyake, Emerson, Padilla, & Ahn, 2004; Saeki & Saito, 2004a, 2004b) and Dunbar and Sussman (1995) found similar results using task-switching paradigms and the Wisconsin Card Sorting Test.

Labeling also appears to relate to performance on EF tasks that measure response control. For example, as noted previously, Luria (1959a) reported that beginning at around 3 years, children can accompany motor responses on a go/no-go task with overt verbal responses on go trials that require them to act, although they cannot use verbal responses to inhibit their motor actions on no-go trials. However, by 4 years, they can use their own, as well as an experimenter's, verbal responses more selectively (see Luria, 1959a, 1961, for more details). Although much of Luria's work on the relation between verbal labels and the development of response control needs replication under tighter experimental conditions, recent work using the Dimensional Change Card Sort and simpler card sorting tasks have supported his findings on preschoolers' ability to use conditional rules (e.g., Zelazo et al., 1996; see Zelazo & Jacques, 1997).

In addition, using a different paradigm, Müller and colleagues (2004) found that labeling helps 3-year-olds succeed on another response control measure of EF. In their interference-control task, children were shown five different-colored Smarties (a popular British and Canadian candy) placed on large mismatching colored cards and were given five smaller colored cards. To win Smarties, the experimenter pointed to one Smartie and children had to give the experimenter a small colored card that matched the color of the larger card on which the Smartie was placed, while refraining from giving the experimenter the colored card that matched the color of the Smartie itself. Most 3-year-olds failed this version of the task, whereas most 4-year-olds did well. However, 3-year-olds did well when asked to label the color of the larger card before reaching for the small card. Interestingly, 3-year-olds also did well when they were asked to point to the larger card before reaching for the smaller card. These findings suggest that labeling or pointing to the larger card itself reoriented children's attention to the color of the card instead of the color of the Smartie as they were required to do, supporting Luria's (1959a) contention that at age 3, children may be influenced by the impulsive attention-directing aspects of labels.

In summary, as children begin to master language, they use labels as a means of decoupling from the immediate stimulus. This makes possible a wide range of cognitive manipulations, leading to advanced EF abilities including flexible thought and response control. In some instances—and shown empirically with 3- and 4-year-olds—the primary function of language is to orient attention toward the appropriate aspect of a situation, a function that can also be accomplished using other external physical cues like pointing. The impressive power of language's influence on EF, however, arises when it leads to the formation of internally generated, conceptual representations. Research on working memory and on other aspects of EF suggests that children spontaneously begin to use language in this way around age 6. Before then, there is a 2- to 3-year period during which these representations can be elicited from children using labeling manipulations, leading to corresponding gains in their executive control abilities.

Internally Generated, Conceptual Representations

As indicated in the previous section, research suggests that how working memory representations are coded may play an instrumental role in the development of cognitive flexibility and response control seen in preschoolers. In particular, advances in EF have been linked to children's tendency to represent information verbally. According to this integration model, one reason why verbal representations may be particularly helpful for EF is that they are necessarily conceptual and abstract as opposed to sensorimotor, allowing children to approach the task using top-down processes as opposed to bottom-up stimulus-driven processes.

To examine links between conceptual representations and EF directly in preschoolers, Blaye and Jacques (2009) used a modified version of a match-to-sample task used in the categorization literature to examine the development of categorical flexibility, the ability to switch successively between two simultaneously available semantic representations of a given object. In the traditional match-to-sample categorization task, children are presented with a target object (e.g., a dog) and asked to match it to an associate from a set of potential matches. Preschoolers are typically presented with a taxonomic choice (i.e., an object that is the same sort of thing; e.g., another animal) and a thematic choice (i.e., an object that is part of the same event or scheme; e.g., a doghouse). Early research suggested that preschoolers have a thematic preference, and that children come to prefer taxonomic matches only later in development (e.g., Smiley & Brown, 1979). Thematic matches are believed to be easier and preferred throughout the preschool period because they presumably can be made on the basis of learned perceptual associations (D'Entremont & Dunham, 1992; Tversky, 1985). In contrast, taxonomic matches require good underlying conceptual knowledge. As a result, these early findings led to the belief that young children do not have a conceptual understanding of taxonomic relations (Inhelder & Piaget, 1959/1964; Nelson, 1977). Recent research has clearly shown that preschoolers can appreciate both kinds of relations, although different contextual variables (e.g., task instructions or presence of labels) can bias children toward one kind of associate over the other (e.g., Blaye & Bonthoux, 2001; Markman & Hutchinson, 1984; Waxman & Namy, 1997; see Murphy, 2002, for a review).

Although a number of studies have claimed to assess categorical flexibility in infants and preschool children (e.g., Blaye & Bonthoux, 2001; Ellis & Oakes, 2006; Mareschal & Tan, 2007), Blaye and Jacques (2009) argued that existing research has not assessed flexibility directly because the same children have not been asked to categorize a specific set of stimuli into different categories successively and without a delay. Therefore, to assess categorical flexibility directly, Blaye and Jacques adapted the traditional match-to-sample categorization task in two ways. In a Double Categorization task (Experiment 1), children were shown a target picture (e.g., a carrot) and three potential matches: a thematic associate (e.g. a rabbit), a taxonomic associate (e.g., a strawberry), and a nonassociate to the target (e.g., binoculars). They were then asked to make *two* successive matches. In a Simple Categorization task (Experiment 2), children also were shown a target picture and three potential matches. However, on thematic trials, they were shown a thematic associate and two nonassociates, and on taxonomic trials, they were shown a taxonomic associate and two nonassociates. Blaye and Jacques found that on the Double Categorization task, 5-year-olds correctly selected both matches for the target more often than 3- or 4-year-olds, whereas on the Simple Categorization task, 4- and 5-year-olds correctly selected both matches more often than 3-year-olds. The authors concluded that, although performance on the Simple Categorization task demonstrates that both 4- and 5-year-olds have the prerequisite conceptual knowledge of both kinds of associates, only 5-year-olds selected both associates when these were placed in competition with each other in the Double Categorization task. These findings indicate that advances in conceptual knowledge may precede advances in categorical flexibility. In support of a direct link between conceptual knowledge and flexibility, Blaye and Jacques also found that children who strategically selected one kind of match (either thematic or taxonomic) consistently across trials in the Double Categorization task demonstrated more flexibility than children who showed less consistency across trials in their Selection 1 responses. In other words, children who used a top-down conceptual strategy to select their first matches across trials were more flexible than those who apparently approached the task on a trial-by-trial basis, presumably influenced by the relative strength of particular associates on each particular trial.

On the basis of findings using the Dimensional Change Card Sort, Kharitonova et al. (2009) also came to the conclusion that children who hold more abstract representations of stimuli are also more flexible. In one version of the Dimensional Change Card Sort, they presented 3-year-olds with test cards that only approximated the target cards on both dimensions. For example, if target cards were a blue truck and red flowers, and children had to sort cards by color, they had to sort turquoise, teal, and green cards with the blue target, and orange, yellow, and orange-yellow cards with the red target. Kharitonova et al. found that switchers (i.e., those who switched on the postswitch phase of a standard version of the Dimension Change Card Sort) had more abstract representations of the stimuli in that they were more likely to sort cards that only approximated the targets with the appropriate target. In contrast, perseverators tended to sort these cards randomly.

In a similar vein, Carlson and colleagues (2005), using a measure of response inhibition—the *Less-is-More task*—argued that redirecting attention from salient perceptual features of rewards by using abstract symbols can provide *psychological distance* between rewards and symbol users, and that this distance, in turn, allows symbol users to show more response control (cf. Sigel, 1970). In the Less-is-More task, children are instructed to point to one of two rewards (e.g., either two or five treats) with the understanding that a naughty puppet will take the reward to which they point and they will receive the remaining one. To succeed, then, children need to point to the smaller reward, while resisting the temptation to point to the reward that they really want. In their study, Carlson et al. (2005) placed rewards in boxes and used symbols on top of the boxes to differentiate them. They included four different symbols, each one increasingly more abstract or distant from the salient features of the reward. In the treats condition, the symbols were identical to the treats; in the rocks condition, the symbols were the same number of rocks and were a similar shape to the rewards but did not share an identity relation; in the beads condition, the symbols were dots drawn in a circle representing a discrete, quantitative representation of the reward; and finally, in the animals condition, drawings of a mouse and elephant represented the quantity relation symbolically using the relative size of the real animals to depict small and large, respectively. Carlson et al. (2005) found that children were more likely to point to the lesser reward box in the most distant symbol condition (the animal condition) than in the least distant one (the treats condition), suggesting that the use of psychologically distant or abstract symbols is more effective at helping children control their behavior than the use of perceptually based ones.

Together, Blaye and Jacques (2009) and Kharitonova et al.'s (2009) findings, as well as those by Carlson et al. (2005), strongly suggest that the representations of children who demonstrate more advanced EF are more conceptual and abstract, and less likely to be perceptually driven than those of children who are less advanced. On the flip side, children and adults who use less abstract representations or who are presented with perceptually salient information have more difficulty controlling their thoughts and behavior (Kirkham et al., 2003; Zaitchik, 1991). For example, Zaitchik showed that 3-year-olds have more difficulty on the false-belief task if they are shown the object in its real hiding location than if they are simply told the location of the hidden object. Likewise, Kirkham et al. showed that 4-year-olds are more likely to perseverate on the Dimensional Change Card Sort if they are required to sort cards facing up across both phases. Seeing the specific cards that they sorted by one dimension in the preswitch phase presumably makes it more difficult for them to sort cards by the alternate dimension in the postswitch.

There is also indirect support for the idea that adults who are overly perceptually driven have more difficulty controlling their behavior. Consider *utilization behaviors* sometimes demonstrated by patients with frontal lobe lesions (Lhermitte, 1983, 1986). Patients who exhibit utilization behaviors—especially environmental dependency syndrome—have exaggerated responses to environmental stimuli and difficulty resisting the temptation to engage in specific actions associated with specific objects when these are presented within their visual field. For example, Lhermitte (1986) reported the case of a female patient, who on being presented with a tongue depressor proceeded to examine the examiner's throat, not because of any previous experience at examining others' throats using tongue depressors (her occupation had consisted of working in the home) or a habit to engage in this particular behavior. Instead, she acted on the basis of what was called for by objects in the immediate environment. It is as though patients with these utilization behaviors cannot overcome the tendency to act on perceptually derived representations of the stimuli by using internally generated representations. The stimuli available in the environment dictate a particular motor response that these patients simply cannot resist doing.

In a rare study that assessed the link between conception and EF in adults, Levine et al. (1995) assessed younger (18–39 years), middle-aged (40–64 years), and older (65–79 years) adults' ability to generate and switch between concepts. They assessed adults on a concept generation task in which participants had to generate six different groupings for six items by separating them into two sets of three items and accurately naming the basis for their groupings. The six items each included an animal word and an abstract figure. The items could be grouped with each other in different ways according to two verbal categories (animal habitat, animal domesticity) and four graphical features (figure shape, figure size, word location, internal properties of the figure). Levine et al. (1995) found that although all age groups attempted the same number of groupings, older adults produced fewer correct groupings, and they erred more often in naming the groups they produced. In addition, older adults were more prone to repeat groupings and names than the younger age groups. However, age group differences were attenuated when the experimenter provided increasingly explicit external cues. For example, all older adults eventually produced the six possible groupings, but many did so only after the experimenter cued them as to how to group items (e.g., "Group the items according to the shape of the figure."). In other words, changing the task from an inductive to a deductive version allowed older adults to identify and switch between all possible groupings. Finally, performance on this task related with measures of cognitive flexibility including the Wisconsin Card Sorting Test and word list generation tasks, suggesting that older adults' difficulties with cognitive flexibility may be related to difficulties in generating appropriate conceptual representations for stimuli.

CONCLUSIONS

Unitary models of EF, unlike diverse models, suggest a single underlying executive process (see Miyake et al., 2000, for further discussion on the distinction between unitary vs. diverse models of EF). However, recent behavioral research suggests that diverse models may be more plausible (Miyake et al., 2000). In this chapter, we proposed that a model that integrates key aspects of existing models into a single model might best account for the development of EF. In particular, the model proposes two major changes in working memory representations that may be important for the development of EF abilities. Specifically, the development of early working memory representations allows infants to gain control over their thoughts and behaviors because they can represent task goals over a delay despite the presence of distractors. These early representations are constructed and supported by sensorimotor representations. In turn, the development of advanced working memory representations allows children and adults to maintain information in mind while processing it simultaneously, permitting them greater executive control abilities. These processing abilities are supported by children's emerging ability to represent information verbally and abstractly (as opposed to perceptually). Although existing empirical research findings are consistent with the features of this model, much research remains to be done to test it directly, especially in older adults, to determine whether this model fits the data better than existing ones. In particular, systematic investigations and comparisons of performance on EF measures across different age groups may help elucidate important information about EF processes themselves and about how these might become linked in development. Moreover, even though neurophysiological findings were beyond the scope of this chapter, these may help to determine the plausibility of specific models of EF. Together, behavioral and neurophysiological data may allow a clearer picture of the nature of interrelations between EF processes throughout the life span to emerge.

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