CHAPTER 14

The Development of Executive Function

ULRICH MÜLLER and KIMBERLY KERNS

INTRODUCTION

Within the scientific literature, the construct of executive function (EF) has received a huge increase in attention over the past three decades. Its growing popularity is reflected in the number of articles published on EF. According to Web of Science, six articles on EF were published between 1981 and 1990, none in the area of developmental psychology. The number of articles grew steadily over the course of the next two decades: 1,156 were published in the period from 1991 to 2000 (159 in developmental psychology) and 8,018 in the period from 2001 to 2010 (789 in developmental psychology). The growth appears to continue unabated, with 5,164 entries listed for the period from 2011 to 2014 (642 in developmental psychology). A further indicator of the popularity of EF is its status as a cross-disciplinary construct that is investigated in a variety of areas, including neuroscience, developmental science, clinical and health psychology, educational psychology, and psychiatry. Indeed, the growing popularity of the construct of EF largely can be attributed to the findings that measures of EF are associated with, and often also predictive of, a host of aspects of psychological functioning and that impairments in EF are implicated in a variety of developmental and acquired disorders.

Although definitions of EF vary considerably, broadly, EF, as a psychological construct, refers to cognitive processes that are required for the conscious, top-down control of action, thought, and emotions, and that are associated with neural systems involving the prefrontal cortex (PFC; Zelazo & Müller, 2010). However, there is no agreement on a more precise definition of EF, and it is widely

Handbook of Child Psychology and Developmental Science, 7th Edition, edited by Richard M. Lerner,

acknowledged that EF is an elusive and ill-defined concept (Jurado & Rosselli, 2007; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Martin & Failows, 2010). In fact, there is not even agreement on the name of the construct as different terms for EF (*executive function [s]/[ing]*, *executive control*, *central executive*, *executive attention*) are frequently used interchangeably. In part, the terminological inconsistency reflects different and incompatible conceptualizations, putting the construct of EF at the risk of theoretical incoherence (Martin & Failows, 2010). Indeed, some researchers have criticized the construct noting that definitions and measures of EF face considerable theoretical and methodological challenges (Barkley, 2012; Dick & Overton, 2010; Martin & Failows, 2010).

What complicates matters further is that EF overlaps with other similarly elusive theoretical constructs, such as self-regulation, self-control, and effortful control. Broadly defined, self-regulation refers to temporally extended goal-directed behavior that entails (a) values, goals, standards of thought, feelings; (b) a discrepancy between standards and the actual state of affairs that the individual is motivated to reduce; and (c) processes employed in the attempt to reduce this discrepancy (Hofmann, Schmeichel, & Baddeley, 2012). Prototypical examples of self-regulation include achievement-related behaviors, personal growth and health strivings, and interpersonal and intimacy strivings (Hofmann et al., 2012). Following this definition, self-regulation is a broader construct than EF because EF typically focuses on the processes that reduce discrepancies between goals and actual states, and the formation of goals, values, and standards is not thematized. In fact, in EF tasks, the experimenter sets the goal for participants, and participants must conform to this goal. The construct of self-control is often used to refer to a narrower and less complex subset of regulatory processes, including compliance and the delay of gratification (Hofmann et al., 2012; Kopp, 1982). Effortful control refers to a higher order temperamental trait that involves both inhibition of prepotent responses and attentional control (Liew, 2011; Rothbart & Rueda, 2005). Often the same tasks are used to assess effortful control and EF. Thus, there is a great deal of conceptual and empirical overlap between effortful control and EF, with the main difference being that these constructs originated in different research traditions.

In this chapter, we review theories and research on the development of EF in children. Given the noted burgeoning amount of research on EF and its development, this review will necessarily be selective. For example, we will not cover EF in developmental disorders such as autism (Pellicano, 2012) or attention-deficit/hyperactivity disorder (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; see Pennington, Chapter 23, this *Handbook*, this volume). In the next section, we trace the history of EF, describe influential contemporary theoretical frameworks of EF, and present the theoretical challenges that these theories face. Next, we review research on neural development and on different aspects of EF. Then we discuss problems related to the measurement of EF, describing a variety of measures of different EF components, examining problems of validity and reliability of EF, and discussing the advantages and disadvantages of performance-based versus rating-scale measures. Following this we review the influence of genetic and social factors and language on the development of, and interindividual differences in EF, followed by a summary of the consequences of interindividual differences in EF for theory of mind and academic readiness and achievement. We conclude with suggestions for future research and an outlook on the direction the field is taking.

EF: ITS HISTORY, CONTEMPORARY CONCEPTUALIZATIONS, AND THEORETICAL ISSUES

In this section, we briefly trace the history of EF to contextualize contemporary conceptualizations and theoretical issues of EF, and evaluate a variety of theoretical approaches to EF and its development. Finally, based on the discussion of the theoretical approaches, we distill a number of theoretical issues that, we submit, each theory of the development of EF needs to address.

History of EF

The construct of EF can be traced back to the second half of the 19th century at a time of remarkable growth in knowledge about the central nervous system (Benton, 1991). At this time, experimental physiologists and early neuropsychologists were intensifying efforts to understand and localize the functions of the PFC. Indeed, this historical origin of the construct of EF has been blamed as being responsible for the current "inherent conflation" of the term *EF* with the functions of the PFC and vice versa (Barkley, 2012), and the context of history of origin also lies at the core of a number of theoretical problems for the construct.

From early on, a major consequence identified as resulting from damage to the PFC were changes in personality, as famously illustrated by Harlow's (1868) case study of Phineas Gage, a railroad worker who suffered from severe damage to the PFC (but see Macmillan, 2000). Welt (1888) linked changes in personality such as increased violence, recklessness, and an addiction to trivial joking (*Witzelsucht*) to damage of the orbital and mesial regions of the PFC, but she also pointed out that lesions to orbital regions of the PFC often do not result in any personality changes. Likewise, a systematic line of research by Jacobsen (1936) substantiated that lesions to the PFC in monkeys and chimpanzees led to deficits in their ability to hold in mind information over a short period of time, as evidenced by their poor performance on the delayed response task (i.e., a delay was interspersed between hiding and retrieval of an object). Thus, evidence from animal studies and clinical observations converged to suggest that lesions to the dorsolateral and orbital regions of the PFC result in distinct patterns of cognitive deficits and personality, motivating the distinction between lateral and orbital symptom clusters or syndromes (Fuster, 2008). The lateral syndrome is characterized by deficits in selective attention, working memory, and planning, and by apathy (Knight & D'Esposito, 2003). The main symptoms of the orbital syndrome are deficient interference control, impulsivity, social disinhibition, and impairment in moral judgment (Fuster, 2008). In addition, Fuster (2008) describes a medial/anterior cingulate syndrome characterized by impairments in voluntary movements and deficits in monitoring and error correction. A similar anatomically based distinction is reflected in the tripartite view of the PFC (Gazzaniga, Ivry, & Mangun, 1998). According to this view, the dorsolateral PFC is associated with working memory and planning functions; the ventromedial PFC is linked to deficits in the social domain, mainly manifest as deficits in social inhibition; and the anterior cingulate is involved in the regulation of attentional systems, monitoring, and error correction.

A concept commonly invoked to explain the deficits following experimentally induced lesions in animals and accidental lesions in patients is the construct of inhibition (e.g., inhibitory control) (Macmillan, 1992). For example, Bianchi (1922) suggested that the function of the frontal lobes is primarily inhibitory. He argued that a more complex form of inhibition ("reasoned inhibition") emerges with the expansion of the field of consciousness, a type of inhibition that coincides "in the zoological scale, with the development of the frontal lobe, and, in ontogenetic development, with the mature growth of that organ" (Bianchi, 1922, p. 331). Reasoned inhibition tempers biological impulses, passions, and egoistic tendencies, and lesions to the frontal lobe negatively affect its influence on behavioral control.

As research on the frontal lobes gathered momentum, knowledge about the observed behavioral consequences of lesions to the frontal lobes increased. An influential account to capture the plethora of consequences was provided by Goldstein (1944; Goldstein & Scheerer, 1941). Goldstein claimed that the frontal lobes are the neurological underpinnings for a higher level of functioning that he termed the abstract attitude and contrasted with the concrete attitude. The concrete and the abstract attitudes "*are capacity levels of the total personality*" that form the "basis for all performances pertaining to a specific plane of activity" (Goldstein & Scheerer, 1941, p. 1; emphasis in original). In the concrete attitude, action lacks self-consciousness and is directly determined by the stimuli in the immediate situation. By contrast, in the abstract attitude, the person interprets the situation from different perspectives, picks out the aspect that is essential, and acts in a way appropriate to the whole situation. The abstract attitude manifests itself in and is the basis for any type of a number of abilities, including categorical behavior (i.e., behavior in which an individual item is seen as a representative of its category), imagination, choice (which requires the generation of possibilities and thus the transcendence of the immediate situation), shifting, and detaching the ego from the outer world and inner experience. In healthy individuals, concrete behavior is initiated and regulated by the abstract attitude. Goldstein noted that healthy individuals can shift from the concrete to the abstract attitude; patients with lesions to the frontal lobe cannot because their concrete behavior is no longer functionally *controlled* by the abstract attitude. Lesions to the frontal lobes thus lead to de-differentiation of function and to an isolation of the activity of parts of the brain from the activity of the rest of the brain (Goldstein, 1944; Goldstein & Scheerer, 1941). Goldstein's theoretical framework captures numerous sequelae of frontal lesions, but his concept of abstract attitude remained too broad and unspecific to move the field forward (Benton, 1991). Moreover, even though Goldstein (Goldstein & Scheerer, 1941, p. 8) acknowledged that there are different levels of concrete and abstract behavior, he did not specify these levels, a mistake corrected by contemporary theories of PFC function that distinguish between different levels of abstraction (Badre, 2008).

A more dynamic and developmental conception of the working of the brain in general and the PFC in particular is implied in Luria's (1966, 1973) suggestion that all regions of the brain should be considered a functional system.

Function here refers to the "organism's complex adaptive activity, directed toward the performance of some physiological or psychological task" (Luria, 1966, p. 24). Functional systems consist of multiple components, located at different levels and oriented toward the performance of a particular task, but the task may be performed by variable neurophysiological and psychological processes. Thus, Luria reasoned mental activity cannot be localized in particular areas of the brain or considered a direct *function* of a limited group of cells, but rather, complex mental activity is hierarchical in structure and is "organized in systems of concertedly working zones, each of which performs its role in a complex functional system, and which may be located in completely different and often far distant areas of the brain" (Luria, 1973, p. 31). As a consequence, Luria reasoned, a lesion of any component of a functional system could lead to disintegration of the entire functional system; thus loss of specific functions cannot be circumscribed to a particular area of the brain. Likewise as function is distributed, the system as a whole can be disturbed by lesions in a very large number of brain regions, and disturbed differently depending upon the region lesioned.

Luria (1973) identified three hierarchically organized and reciprocally coordinated functional units that he proposed are involved in any mental activity. He noted the PFC plays a particularly important role in the functional unit responsible for higher mental activity, including the formation of intentions and action programs, and the regulation, and verification of mental activity and actions. Drawing on the work of Vygotsky (1934/1997), Luria (1973) held that higher mental functions are not ready-made at birth but develop in the context of social interaction. Thus, higher mental functions are social in nature, and mediated by socially constructed *sign systems* such as language. These sign systems drive the establishment of functional connections between different parts of the brain and are instrumental in the creation of more complex functional systems: "*Historically* [i.e., in the course of development; U. M. & K. K.] *formed measures for the organization of human behavior tie new knots in the activity of man's brain* . . . and it is the presence of these functional knots . . . that is one of the most important features distinguishing the functional organization of the human brain from an animal's brain (Luria, 1973, p. 31; emphasis in original). Consequently, the functional process of any conscious mental activity changes with development, as does its neural organization, in that the activity starts to depend on a different system of concertedly working zones. The organization among functions also changes in that throughout development, structurally higher forms of activity exert a downward influence on structurally lower forms of mental activity, and higher cortical zones start to control lower cortical zones. A major task for developmental neuropsychologists, then, is to determine the relations between working zones and the particular contribution of each working zone to the functional system at different periods, as this varies across development. Several aspects of Luria's theory are remarkably current, particularly the notion of hierarchically organized functional systems and the proposal that higher mental functions are rooted in social interaction.

The term *executive function* itself was introduced by Karl Pribram (1973, 1976) in the context of explaining the consequences of lesions to the PFC in monkeys and humans. According to Pribram (1973), the function of the PFC is to structure behavior in situations with variable cue–response contingencies (e.g., tasks in which the hiding location changes according to a particular rule). In such situations, the PFC is necessary to extract a higher order regularity ("second-order invariants") to create a context on which to base behavior. At about the same time, cognitive psychologists (broadly influenced by expanding artificial intelligence and mechanistic technologies) Baddeley and Hitch (1974) introduced the notion of the central executive, a component of working memory that controls the flow of information to and from other working memory systems. Thus, the ideas of EF and a central executive emerged in the psychological literature around the same time.

By the mid-1970s, then, the stage had been set for launching research on EF, but it still took about two more decades until it made its appearance in the developmental psychology literature. A number of reasons account for this delay. First, an early, influential idea held that the PFC was not functional during early childhood (Luria, 1973) and possibly not even until adolescence (Golden, 1981). Second, because EF tasks were originally created for use with either adult patients with lesions to the PFC or animals, until recently very few child-friendly or appropriate measures of EF were available (Hughes & Graham, 2002).

To summarize, historically, the term and the construct of EF can be traced back to clinical neuropsychological research on the behavioral consequences of damage to PFC. The term was intended to capture the psychological abilities whose impairment was presumed to underlie the manifest deficits in patients with PFC damage. Because these consequences are numerous and diverse, and are frequently described as a list of partially overlapping deficits, the conceptualization of EF faces considerable challenges, as we describe in the following section.

Executive Function Lists

As the use of the term *EF* has exploded in the literature over the last 20 years, researchers have faced the challenges of providing a precise definition of EF, delineating the phenomena that fall under its purview, and explaining these phenomena by one or more underlying cognitive processes. At present, the term *EF* remains poorly defined and thus ambiguous. Indeed, in a survey of neuropsychologists, Eslinger (1996) found that 33 different concepts were associated with EF, giving rise to the seemingly anarchic state of affairs such that EF could mean anything the researcher wants it to mean (Barkley, 2012).

Confronted with the heterogeneity of varying consequences of lesions to various aspects of the PFC, researchers often have resorted to making lists of abilities that have been associated with the PFC. These lists include planning, judgment, concept formation, abstract thinking, decision making, cognitive flexibility, use of feedback, impulse control, synthesis of multiple pieces of information across time and space, attention, temporal ordering of events, divergent production of ideas, fluid or general intelligence, monitoring one's own actions, self-regulation, and self-perception (see, for example, Grattan & Eslinger, 1992; Tranel, Anderson, & Benton, 1994). Unfortunately, such lists combine abilities of different levels of abstraction, and some of these abilities (e.g., judgment, abstract thinking) are too broad to be helpful in truly elucidating the concept of EF. We now turn to attempts of explaining EF and its development.

Developmental Theories of EF

Theories of the development of EF can be categorized into different types (Martin & Failows, 2010). Whereas narrowing accounts focus on one component process of EF and attribute the development of EF to this component, widening accounts focus on several component processes of EF. We discuss inhibition and working memory theories as examples of the narrowing accounts, and the working memory plus inhibition account as an example of a widening account. In this context, we also discuss factor-analytic approaches to EF, popular in the area of developmental psychology. The computational modeling approach to EF has received considerable attention. Applied to development, the goal of computational modeling is to provide a rigorous mechanistic explanation of how the development of EF proceeds. In principle, this approach is compatible with both narrowing and widening accounts. In this section, we discuss Munakata's (Morton & Munakata, 2002; Munakata, Snyder, & Chatham, 2012) influential neural network model to illustrate the computational modeling approach to EF. Finally, we examine functional and hierarchical accounts of the development of EF. Functional accounts fall under widening accounts because they treat EF as a macroconstruct that is composed of a number of temporally distributed subfunctions that serve distinct roles in achieving a particular outcome. We present two functional approaches that are closely tied to a hierarchical account of EF. Hierarchical accounts propose that EF is structured in terms of different levels of control, typically with higher levels exerting control over lower levels.

Inhibition Accounts

The concept of inhibition or inhibitory control has a long and checkered history in psychology (Macmillan, 1992). It is used to explain a variety of different behaviors, ranging from behavioral extinction to the repression of memory (Aron, 2007). Several contemporary theories of EF view inhibitory control as an independent process, the development of which explains children's ability to regulate and control their thoughts, behaviors, and emotions (Dempster, 1992; Diamond, 2013). Prima facie, increases in inhibitory control provide a plausible explanation of why children learn to go against their habit or resist temptation, an idea expressed by Diamond's (2013, p. 137) statement that inhibitory control is required whenever we need to "override a strong internal predisposition or external lure, and instead do what's more appropriate or needed . . . having the ability to exercise inhibitory control creates the possibility of change and choice."

One vexing problem that has faced the concept of inhibition throughout history is the heterogeneity of the phenomena that it is called upon to explain (Macmillan, 1992). The different uses of the construct of inhibition have led to the conclusion that "inhibition is at present not a coherent theoretical entity" (MacLeod, 2007, p. 16). In response to this unsatisfactory state of affairs, researchers have developed taxonomies that distinguish between different types of inhibition. Harnishfeger (1995) suggests that inhibitory processes can be classified along three dimensions: (1) intentional versus automatic (i.e., occurring outside conscious awareness); (2) cognitive (i.e., suppressing irrelevant ideas in working memory) versus behavioral (i.e., suppressing an overt response as in motor inhibition or impulse control), and (3) cognitive inhibition and interference control, with the latter referring to a more passive gating mechanism that prevents interference under conditions of multiple distracting stimuli. Nigg (2000) distinguished between effortful inhibition of motor or cognitive responses and automatic inhibition, and classified the effortful inhibitory processes into four types (interference control, cognitive inhibition, behavioral inhibition, and oculomotor inhibition) and automatic inhibitory processes into two types (inhibition of return, inhibition of information at unattended locations). Friedman and Miyake (2004; see also Casey, 2001) point out that the different types of inhibitory processes correspond to different stages in information processing. Resistance to interference takes place at the perceptual stage of processing, where relevant information must be selected and irrelevant information must be ignored. Cognitive inhibition takes place in working memory, and behavioral inhibition resolves response conflict at the output stage.

Fractionation of inhibition is supported by factor-analytic studies. Using an adult sample, Friedman and Miyake (2004) found that the ability to suppress prepotent responses was closely related to the ability to resist interference from distraction, and that both were unrelated to the ability to resist intrusions from no longer task-relevant information ("resistance to proactive interference"). These findings thus support a response–distractor versus proactive interference taxonomy. Developmental studies have similarly failed to find a unitary inhibition factor (Huizinga, Dolan, & van der Molen, 2006; van der Sluis, de Jong, & van der Leij, 2007), and a study that controlled for attentional activation found support for the distinction between effortful inhibition (e.g., stop-signal task) and automatic inhibition (e.g., flanker task; Howard, Johnson, & Pascual-Leone, 2014; for detailed description of these tasks see below). Even though the dimensionality of inhibitory control has to be clarified further, existing evidence clearly suggests that researchers need to specify the type of inhibition they are referring to when discussing inhibitory functions and their role in the development of EF.

The construct of inhibition has been criticized for a number of further reasons (for an extended discussion, see MacLeod, 2007; MacLeod, Dodd, Sheard, Wilson, & Bibi, 2003). First, in many tasks that allegedly involve inhibitory mechanisms, performance can be explained equally well by noninhibitory mechanisms (MacLeod, 2007; MacLeod et. al, 2003). To illustrate, the Stroop task is often considered a measure of interference control. In this task, participants are presented with color words written in an incongruent ink color (e.g., the word *blue* written in red), and they are asked to name the ink color, thereby presumably inhibiting the automatic tendency to read the word. Using an elegant statistical approach to this task, Bub, Masson, and Lalonde (2006) found larger interference effects for color-naming trials on the Stroop task in children between 7 and 9 years old than in children 9 to 11 years old, but, as demonstrated by an analysis of the response time distributions, younger children showed evidence of more, and not less, suppression of word reading. Consequently, poor inhibitory abilities could not account for the younger children's performance; instead, Bub and colleagues reasoned that Stroop interference resulted from the inability to maintain task set in color naming.

A second criticism of inhibition accounts is that they are incomplete because inhibition is only a "negative" mechanism that prevents the production or execution of a response, but it does not explain how eventually the correct response is produced (Roberts & Pennington, 1996). Inhibition accounts thus still need to explain how children generate the correct response. Third, inhibition is often invoked to explain perseveration. For example, 10-month-old infants perseverate in the A-not-B object search task: After having found the object repeatedly under Occluder A, and seeing it disappear under Occluder B, they will continue to search under A, where they previously retrieved the object. However, this type of explanation (i.e., explaining perseveration by deficits in inhibition) could be considered circular because *explanandum* (cannot stop the behavior) and *explanans* (inhibition) do not appear to be independent. Furthermore, inhibitory theories also need to explain why children perseverate on different tasks at different ages. If proponents of an inhibition account propose that children perseverate on different tasks at different ages because these tasks differ in terms of inhibitory demands, then they need to develop a metric that provides clear rules on how to determine the amount or complexity of inhibitory demands. Finally, several researchers have suggested that inhibition is not an independent process but a side effect of working memory activation; we discuss this idea in the next section.

Working Memory Accounts

The construct of working memory refers to a capacity-limited system that holds information in mind for short periods of time and simultaneously operates on this information. There are several different models of the structure of working memory, but there is general agreement that working memory is comprised of a storage system and control system. A model that has been very influential in developmental psychology is Baddeley and Hitch's (1974) model of working memory that was originally composed of three main components: the central executive, the phonological loop, and the visuospatial sketchpad. The central executive acts as a flexible control system that focuses, divides, and shifts attention (Baddeley, 2012). The phonological loop processes auditory verbal information and the visuospatial sketchpad processes visual information. The later added episodic buffer holds integrated episodes in a multisensorial code and acts as a link between the different working memory systems, long-term memory and perception (Baddeley, 2012). Developmental research that has drawn on Baddeley's model has traced the development of the different working memory systems and investigated the structure of working memory at different ages (e.g., Gathercole, Pickering, Ambridge, & Wearing, 2004; Schmid, Zoelch, & Roebers, 2008). A more detailed account of the mechanisms that determine working memory capacity has been offered by Cowan (2005) and Engle (2002; Engle & Kane, 2004). Similar to Baddeley, Engle and colleagues consider the ability to control attention in a goal-directed manner ("executive attention") as the central function of working memory. Individual differences in working memory capacity manifest themselves as differences in the ability to allocate attention flexibly and to inhibit irrelevant thoughts and distracting events (Redick, Heitz, & Engle, 2007). Thus, according to Engle and colleagues (see Redick et al., 2007), inhibitory ability is dependent on working memory capacity.

Working memory accounts consider EF not as a superordinate construct but as the outcome of the development of the central executive or working memory capacity. The working memory account thus attempts to derive other component processes of EF from working memory.

Working Memory Plus Inhibition Accounts

Roberts and Pennington (1996) suggested an interactive framework for considering the relation between working memory and inhibition. According to this framework, working memory activation of a particular goal-oriented action leads to automatic inhibition of nonselected actions. Working memory and inhibitory demands of a task draw on the same pool of executive resources. Consequently, performance on EF tasks can be disrupted in one of two ways: (1) the working memory load is increased (e.g., by having a person perform a secondary task), so that fewer resources are available for the inhibition of prepotent actions; (2) the strength or prepotency of response alternatives is increased such that more working memory activation is required to inhibit incorrect responses. Developmental increases in working memory capacity then account for age-related improvements on EF tasks.

Beveridge, Jarrold, and Pettit (2002) devised an elegant test of the interactive framework. They reasoned that working memory and inhibitory demands interact only if sufficient demands are placed on the pool of executive resources. If demands are light, the effects on the executive system will only be additive. The assumption underlying these predictions is that the executive system has linear operating characteristics up to the point at which its resources are exhausted, and that beyond this point increasing demands will have a disproportionately adverse effect on performance. To test these predictions, Beveridge and colleagues administered three EF tasks to 6- and 8-year-old children. In each task, they independently varied working memory load and prepotency. For example, in a continuous performance task (CPT) children were asked to respond to target stimuli and withhold a response to others. CPTs require both inhibition (withholding a response to nontargets) and working memory (holding in mind which stimuli to respond to recognizing targets). Beveridge and colleagues varied working memory demands by using a different number of targets in different conditions, and they varied inhibitory demands by altering the frequency with which targets appeared in the different conditions (i.e., frequent targets will increase prepotency). Overall, there were main effects for working memory and inhibitory load, but there were no interactions between working memory and inhibitory load. However, as Beveridge and colleagues acknowledge, the manipulations used in their study may not have placed a sufficient load on working memory and inhibition. Therefore, it would be premature to reject the possibility that high working memory and inhibitory loads make demands on a common executive resource, and more research is necessary to clarify whether working memory and inhibition are independent or interdependent executive processes, and whether the relation between working memory and inhibition is task dependent.

Factor-Analytic Approaches to EF

One major issue in the conceptualization of EF concerns the question of whether EF is a unitary construct or a heterogeneous set of dissociable processes (Garon, Bryson, & Smith, 2008; Jurado & Rosselli, 2007). One common approach to address this issue has been to devise comprehensive neuropsychological test batteries and to use principal components analysis (PCA) or exploratory factor analysis (EFA) to determine whether the manifest variables can be reduced to a smaller number of underlying factors. Developmental studies using PCA and EFA have generally revealed between one and four factors of EF in preschool children (e.g., Carlson & Moses, 2001; Espy, Kaufmann, McDiarmid, & Glisky, 1999; Hughes & Ensor, 2007; J. A. Welsh, Nix, Blair, Bierman, & Nelson, 2010), and three factors in school-age children (e.g., Brocki & Bohlin, 2004; for a detailed summary, see Zelazo & Müller, 2002).

The factorial solutions derived in these studies differ in terms of the number, composition, and interpretation of the extracted factors, limiting the conclusions about the nature of EF that can be drawn from these studies. Inconsistencies may be due to the use of different test batteries, to the age ranges of the participants, and low reliability of the EF measures (van der Sluis et al., 2007; Willoughby & Blair, 2011). Indeed, the underlying factors confirmed within this approach are necessarily constrained and identified solely by the tasks or measures included in the analysis. Furthermore, many PCA and EFA studies have used varimax rotation in an attempt to restrict the factor solution to uncorrelated or orthogonal (dissociable) factors, which tends to produce factors that are sample specific and difficult to replicate (Gorsuch, 1997; Wiebe, Espy, & Charak, 2008).

A further reason of why PCAs and EFAs have produced inconsistent findings is the task impurity problem. Task impurity refers to the problem that tasks designed to measure EF typically involve a variety of nonexecutive processes (see Hughes & Graham, 2002). As a consequence, different tasks may load on a factor, not because they make similar executive demands, but because they share nonexecutive processes (e.g., reading speed, motor speed). A more promising approach to clarifying the structure of EF consists of using confirmatory factor analysis (CFA). In CFA, researchers use a priori hypotheses to stipulate that specific tasks load on an underlying latent variable; the stipulated structure or model is then evaluated to determine how well it fits the data (Bryant & Yarnold, 1994). Because CFA extracts only the variance that is common to the tasks that are supposed to measure the same executive process, the common factor underlying the performance on these tasks has been suggested to be a better measure of EF than the individual tasks used to identify the factor. It should be noted, however, that CFA cannot rule out the possibility that the latent factors still emerge due to shared variance among non-EF processes.

The use of CFA for determining the composition of EF has been pioneered by Miyake et al. (2000), and their seminal work has served as a template for many studies on EF. Based on a prior literature review, Miyake et al. (2000) stipulated three basic EF component processes: (1) inhibition of prepotent responses, (2) shifting between mental sets, and (3) updating and monitoring representations in working memory. They designed relatively simple tasks to measure each component and administered these tasks to adults. For example, they used the Stroop test to measure response inhibition; Shifting was measured by the number–letter task, in which participants were instructed to shift between judging digits (odd versus even) and letters (consonant versus vowel) depending on where these symbols were located on a computer screen. Finally, an updating task was the letter memory task, which required participants to remember the last four letters in a list. CFA analyses revealed that, as theoretically predicted, the different elementary tasks loaded on the inhibition, shifting, and updating factors, and these factors were moderately correlated, "thus indicating both unity and diversity of EFs" (Miyake et al., 2000, p. 87).

Further work has led to the reinterpretation of the factor structure. Friedman, Miyake, and colleagues (Friedman et al., 2008, Friedman, et al., 2011) now decompose each EF factor into variance that (a) is shared by the three latent factors (common EF) and (b) is unique to each EF factor (i.e., inhibition-specific, updating-specific, and shifting-specific processes). After accounting for common EF, however, there was unique variance left only for an updating factor and a shifting factor, but not for an inhibition factor. Based on this work, Miyake and Friedman (2012, p. 11) suggested that the common EF factor reflects the "ability to actively maintain task goals and goal related information and use this information to effectively bias lower-level processing."

To date, there have been several applications of CFA to EF involving preschool and school-age children. A number of CFA studies involving a variety of EF tasks have tended to support a unitary EF factor structure in preschoolers (Fuhs & Day, 2011; Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al., 2008; Wiebe et al., 2011; Willoughby, Blair, Wirth, & Greenberg, 2010, 2012; Willoughby, Wirth, & Blair, 2012). However, in most of these studies, a two-factor EF structure consisting of working memory and inhibition still fit the data well, but was rejected in favor of a unitary structure on grounds of parsimony. Other latent variable studies have found that a two-component EF structure with working memory and inhibition as latent factors fit the data better than a unitary EF structure both in typically (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012; Usai, Viterbori, Traverso, & De Franchis, 2014) and atypically developing preschoolers (Schoemaker et al., 2012). Studies with school-age children provide evidence for a more differentiated factor structure, with two studies (Lehto et al., 2003; Rose, Feldman, & Jankowski, 2011) replicating the factor structure that Miyake and colleagues (2000) found for adults, and two studies (Huizinga et al., 2006; van der Sluis et al., 2007) finding evidence for a working memory and a shifting factor, but failing to find a single common inhibition factor due to low correlations between the measures of inhibition. Two further studies found that a two-factor model with a combined inhibition and shifting and a working memory factor was the best fitting model for 6- to 8-year-olds (Van der Ven, Kroesbergen, Boom, Leseman, 2013) and 5- to 13-year-olds (Lee, Bull, & Ho, 2013). Furthermore, Lee and colleagues found that the tripartite model with inhibition, shifting, and working memory was the best-fitting solution for 15-year-olds.

Overall, this pattern of findings supports the differentiation hypothesis of the functional organization of cognitive abilities (Garrett, 1946). This hypothesis states that development proceeds from a relatively undifferentiated and global state toward increasing differentiation and articulation (Werner, 1957). It is also consistent with the interactive specialization theory of brain development, according to which neurocognitive development consists of an increasing functional specialization of neural systems that are initially relatively undifferentiated but become more specialized as a result of interactions between individual and environment (Johnson & Munakata, 2005; see also Pennington, Chapter 23, this *Handbook*, this volume; Stiles, Brown, Haist, & Jernigan, Chapter 2, this *Handbook*, this volume). Conceptualizing the development of EF as a differentiation process, however, raises a number of interesting questions. For example, what are the factors and experiences that lead to the differentiation? What kind of factor structure is the developmental outcome? What are the reasons for the emergence of a particular factor structure (e.g., why can EF be fractionated into working memory and flexibility, but not, say, into error detection and planning)? Finally, it is unclear how to interpret the unitary factor or the significant amount of variance shared among factors (Lee et al., 2013; Miller et al., 2012; Van der Ven et al., 2013). One candidate is the ability to maintain goal-relevant activation (Miyake & Friedman, 2012; Wiebe et al., 2008); another candidate is processing speed (Rose et al., 2011). Support for the processing speed hypothesis comes from studies that have shown that age-related improvements in response inhibition and working memory are largely mediated by concomitant improvements in processing speed (McAuley & White, 2011), and that speed of habituation in infants predicts EF in early adolescence (Rose, Feldman, & Jankowski, 2012).

Even though there appears some convergence among CFA studies of the development of EF, these findings are not entirely consistent. The inconsistencies across studies have been attributed to a variety of reasons, including the reliance on different scoring systems, task selection, the use of an insufficient number of indicators per latent variable, and the failure to test alternative factor models (for a discussion, see Miller et al., 2012; Lee et al., 2013; Van der Ven et al., 2013). Blair and Willoughby (2013) raise more fundamental concerns about the usefulness of CFA in clarifying the dimensionality of EF. They point out that correlations among EF tasks are typically very low in preschoolers ($r = .20$), resulting in very little variation that is shared across task indicators in the CFA. Thus, the majority of variance of each task indicator does not contribute to the latent variance term (i.e., the understanding of individual differences in EF), and its factor loadings are rather low. As a consequence, the amount of variance in the tasks indicators explained by each latent variable is rather small: "The result is that latent variables of EF may not represent either the broad or narrow set of abilities articulated at the outset. Instead, latent variables of EF tasks may actually represent individual differences in general abilities (e.g., sustained attention, behavioral compliance, intelligence) that are required for the completion of any novel task in a controlled testing environment" (Blair & Willoughby, 2013, p. 351). In a similar vein, Van der Ven and colleagues (2013, p. 84) raise the possibility that "factors supposedly reflecting higher order executive processes may instead be mere statistical by-products of the concerted actions of a variety of lower order processes, both processes related to executive control and non-executive processes." They suggest that instead of fractionating the EF into broad factors, a better direction to take in future research might be to focus on lower level processes and their interactions.

Computational Approaches to EF

The computational approach by Munakata is likewise guided by the assumption that improvements in working memory drive the development of EF. This approach relies heavily on neural network modeling. These models "simulate neural properties and functions in a mathematical form, allowing one to manipulate and test how specific aspects of the brain and its development might contribute to cognition and behavior" (Munakata, Chatham, & Snyder, 2013, p. 188). Neural network modeling offers the possibility to put hypotheses about the neural mechanisms that drive changes in EF to a rigorous test by instantiating these mechanisms in a neural network and observing whether they produce the stipulated outcome.

Morton and Munakata's (2002) connectionist model to explain children's performance on a number of EF tasks represents one example of a neural network model. This neural model consists of an input layer, an output layer, and a layer of hidden units. Each layer, in turn, is composed of units that interact with each other through different types of connections. Feed-forward connections are established between units of the input layer and the hidden layer and between units of the hidden layer and the output layer, and the strength of these connections changes according to the Hebbian learning rule (i.e., connections between units that are simultaneously active are strengthened). These feed-forward connections are latent traces that reflect the associative strength that has been formed as the result of the prior interactions between the system and the world. According to this connectionist model, EF is driven by age-related increases in the strength of the recurrent excitatory connections of the units within the PFC that allow the system to sustain active memory representations. As active memory representations get stronger, they override latent memory traces. For example, in the Stroop task when a person is presented with color words (e.g., red) printed in nonmatching colored ink (e.g., blue ink), and required to name the color of the ink, the automatic tendency to read the word (e.g., red) must be overridden by sustaining the active representation of the task instructions to name the color (e.g., blue).

According to the connectionist model, inhibition is not an independent, specialized process but an effect of representing and maintaining abstract information (e.g., goals) in the PFC (Munakata et al., 2011). Specifically, Munakata and colleagues suggest that the representation and maintenance of goal-relevant information in PFC serves as a framework for understanding different types of inhibitory effects: (a) direct global effects (e.g., pausing of motor outputs), and (b) indirect competitive effects (i.e., goal-relevant information in PFC activates representations downstream, thereby effecting collateral inhibition of competitors).

Munakata and colleagues (2012) highlight the role of abstract and robust goal representations maintained in working memory in supporting three key transitions in childhood. First, the maintenance of abstract goal representations such as task rules (e.g., sort by color) provides top-down support for children to adjust their responses flexibly to changing contexts, and it helps children to overcome habitual, perseverative responses. Second, the ability to maintain robust representations leads to the transition from reactive to proactive control. This transition is illustrated in an AX version of the continuous performance task used by Chatham, Frank, and Munakata (2009) with 3- and 8-year-olds. In this task, participants had to make a target response (i.e., pressing a happy-face button) to a frequent sequential stimulus pair (e.g., SpongeBob [denoted A] followed by a watermelon [denoted X]) and nontarget response (sad-face button) to all other stimulus combinations (e.g., blue [denoted B] followed by a slinky [denoted Y]). Chatham et al. (2009; see also Lorsbach & Reimer, 2010) found that 8-year-olds had relatively more difficulty than 3-year-olds when the A stimulus was followed by the Y stimulus, suggesting that they had prepared a target response. By contrast, 3-year-olds had more difficulties when the first stimulus was a B and thus fully predicted a nontarget response, suggesting that they had not prepared a non-target response. Together with the finding that 3-year-olds exerted more effort (as indexed by pupil diameter) after the second stimulus and 8-year-olds after the first stimulus was presented, Chatham et al. interpreted these findings as evidence that 8-year-olds maintained the first stimulus in working memory and proactively prepared for a response, whereas 3-year-olds retrieved the first stimulus retroactively after the second stimulus (X) had been presented.

Third, the transition from externally driven to self-directed control is also supported by the development of more abstract and robust goal representations in working memory. To illustrate, externally driven control is implied when children need to be reminded to clean up their toys, whereas endogenous self-directed control does not rely on external prompts but is self-initiated. Snyder and Munakata (2010) used a category fluency task to study endogenously driven switching. In the category fluency task, children are given a time limit (e.g., 1 minute) to say as many members from a particular category (e.g., food) as possible. Performance on this task improves when participants produce items by subcategory (e.g., breakfast food, dessert, etc.) and switch subcategory when needed. Thus, better performance on this task requires that participants themselves determine when to switch and what category to switch to. Snyder and Munakata (2010, Experiment 3) found that 5-year-old children who were provided with subcategory labels (e.g., dessert) during the fluency task generated more words and switched subcategories more frequently than children provided with exemplars (e.g., cupcake). Snyder and Munakata attribute the better performance in the subcategory condition to the reduction of competition among alternative responses, which they believe is a major difficulty children encounter in the category fluency task. Subcategorization helps performance because, instead of all items in the category, only the items in the subcategory compete for the response, and when a subcategory has been exhausted, only a limited number of subcategories compete for a response. Abstract representations in the form of subcategories that include lower level exemplars thus provide top-down support for generating subcategory members, thereby restraining the search space and reducing selection demands.

Munakata's computational model has been shown to simulate performance on a variety of EF tasks (e.g., Morton & Munakata, 2002; Munakata, 1998) and presents a remarkable attempt to unify numerous phenomena and explain important qualitative transitions in children's cognitive control. Indeed, the transitions from reactive to proactive control and from exogenous to endogenous control describe two important changes in the development of cognitive control that have not received sufficient attention (but see Piaget's [1975/1985] α, β, and γ reactions). As Munakata and colleagues (2012) point out, the shift from reactive to proactive control and from externally to internally driven control may occur for different tasks at different points in time, depending on the level of abstractness of the representation that is involved and how long active representations need to be maintained. However, the status of abstract representations in the network model needs to be further clarified. Abstract representations provide top-down support for relevant category members by coding for their shared feature(s) and ignoring irrelevant features (Snyder & Munakata, 2010). In the neural network, abstract representations emerge when a representation (e.g., coding for the dimension of color) is activated in the PFC units while individual category exemplars are presented (Munakata et al., 2013). This conceptualization of the emergence of abstract representations is reminiscent of the empiricist abstraction theory of concepts (e.g., Hull, 1920) that places emphasis on representations instead of mental operations or processes (see Cassirer, 1923/1953). As a consequence, the neural network approach faces the same kind of problems as the empiricist abstraction theory. For example, it is unclear what an abstract representation exactly is. As Cassirer (1923/1953) has pointed out, we do not arrive at abstract concepts by simply eliminating features of individual exemplars:

> When we form the concept of metal by connecting gold, silver, copper and lead, we cannot indeed ascribe the abstract object that thus comes into being the particular color of gold, or the particular luster of silver, or the weight of copper, or the density of lead; however, it would be no less inadmissible if we simply attempted to deny all these particular determinations of it. For the idea obviously does not suffice as a characterization of metal, that it is neither red nor yellow, neither of this or that specific weight, neither of this or that hardness or resisting power, but the positive thought must be added that it is colored in *some* way in every case, that it is of *some* degree of hardness, density and luster. (pp. 21–22; emphases in original)

It is unclear how in the neural network account the abstract representation captures the features of the individual exemplars. Furthermore, how is it possible for the notions of dimension or generality to emerge by coding for common features? It appears that the neural network only learns that something is red because something else is red, and so on (Husserl, 1900/1970). In fact, it might even be questioned whether the model learns an abstract representation at all because the point of view from, and respect in, which the different exemplars are alike is provided to the model from the start. Clearly, the notion of abstract representations in the neural network account of Munakata and colleagues needs to be elaborated.

Hierarchical and Functional Approaches to EF

Vygotsky (1934/1997) argued that it would be a limiting view of higher centers in the brain to reduce their function to the inhibition of or sensitization to the activity of lower centers. He believed that the "specific function of each special intercentral system is first of all to provide for a completely new, productive form of conscious activity and not just one that inhibits or stimulates the activity of lower centers" (p. 142). In contemporary theories of the PFC, this idea has taken the form of hierarchical control (e.g., Botvinick, Niv, & Barto, 2009; Koechlin & Summerfield, 2007). Badre (2008, p. 193) distinguishes between processing and representational hierarchies:

> Processing hierarchies require that superordinate levels, operating over longer time scales, asymmetrically modulate subordinate processing. Representational hierarchies require that superordinate representations form abstractions over subordinate representations, favouring generality over detail and allowing information to be inherited asymmetrically from higher to lower levels.

Following this distinction, Munakata's computational model (see previous section) falls in the class of representational hierarchical models.

In the next section, we summarize and evaluate two theories of EF that combine a structural-hierarchical and functional approach. The first is Fuster's theory of PFC functions, and the second is Zelazo's theory of the development of EF.

Fuster's Theory of Prefrontal Functions

According to Fuster (2008), the dynamics of the PFC follows two basic principles: First, similar to Luria's (1966, 1973) notion of functional systems, goal-directed sequential actions have a particular temporal gestalt that is defined by the goal of the action and the relations among its components. Fuster stresses the holistic character of the gestalt, in particular the idea that the relations between components of goal-directed actions are critical. The second principle is that goal-directed sequential action arises in the context of the dynamic interplay between the organism and its environment, which Fuster terms the perception-action cycle. Perception and action are intrinsically related through a variety of feedback loops that occur at a number of levels in a dual hierarchical system, with the perceptual hierarchy located in the posterior cortex, and the action or executive hierarchy located in the frontal cortex. With ascent, the perceptions and actions represented in both hierarchies become increasingly more abstract. For example, the goals of behavior become more distant in time and include increasingly more subordinate actions. The higher levels of the hierarchy activate and exert top-down control on lower levels (e.g., activation of an action goal in PFC travels downstream to activate the premotor cortex), and they receive feedback from lower levels that allows higher levels to monitor lower levels.

Fuster (2008, p. 363) argues that the primary role of the PFC consists in the temporal integration and synthesis of behavioral structures, especially those that are novel, and complex. The PFC thus selects and sequences individual actions toward a goal, and makes adjustments as necessary. Two prefrontal mechanisms are essential to this task: (1) monitoring (e.g., monitoring of the outcome of the action, error monitoring) and (2) mediating cross-temporal contingencies (e.g., making sure that the successive actions are executed in the right order). Fuster suggests that working memory and set (i.e., preparation for action) are key temporal integration functions, with working memory representing attention to the past and set representing attention to the future.

Fuster's proposal that temporal integration is the primary function of PFC has interesting implications for conceptualizing EF. Following Fuster, EF is a macro-process that is extended over time and ensures the context-appropriate coordination of actions. Unfortunately, Fuster does not detail how dual and reciprocally connected hierarchies develop. We turn now to a genuinely developmental account that shares with Fuster's account the structural-functional orientation.

Zelazo's Structural-Functional Theory of EF

The account by Zelazo combines a structural and functional approach. Drawing on Luria's concept of functional system, Zelazo, Carter, Reznick, and Frye (1997) suggest that EF should be defined by its outcome, which, they submit, is problem solving. As a complex functional system, EF is temporally extended and consists of a number of distinct subfunctions that are hierarchically organized around the common outcome. Zelazo and colleagues distinguish four temporally and functionally distinct steps in problem solving: (1) representation, which involves the construction of the problem space; (2) planning, which includes devising a plan and sequencing the steps that must be taken to solve the problem in time; (3) execution of the plan, which involves keeping the plan in mind and translating it into actions by using particular rules; and (4) the evaluation of action, which involves both error detection and error correction, the latter of which may result in a change in and resumption of any of the previous phases of problem solving. As reviewed by Zelazo and colleagues (1997), each of the different subfunctions undergoes dramatic changes in early childhood, resulting in significantly improved problem-solving abilities.

One distinct advantage of the problem-solving framework is that it offers a systematic approach to analyse failure on an EF task, and to decompose the task and experimentally manipulate task features in order to determine the source of failure (e.g., Jacques, Zelazo, Kirkham, & Sencesen, 1999). This approach is particularly useful for complex EF tasks that tap numerous executive and nonexecutive processes. A diligent experimental approach might also be able to determine whether failure on complex tasks is due to deficits in any one of the component processes or in the coordination and synthesis of these processes.

Whereas the problem solving framework treats EF as a temporally extended macro-process and describes the hierarchical organization among its distinct phases, Zelazo and Frye's (Frye, Zelazo, & Burack, 1998; Zelazo

& Frye, 1998) cognitive control and complexity theory (CCC theory) presents a hierarchical account of the planning phase of the problem solving process. Specifically, the key claims of CCC theory are that children, when confronted with particular problems, formulate plans in terms of rules, and that there are systematic age-related increases in the complexity of rule systems that can be measured in the number of levels of embedding in these rule systems. These key ideas of CCC theory can best illustrated in the context of a particular task, the Dimensional Change Card Sort (DCCS) test. In the DCCS, children are presented with two target cards (e.g., a red rabbit and a blue boat) and are told a pair of rules for sorting bivalent test cards (e.g., blue rabbits and red boats) according to only one dimension (e.g., color). After children sort several test cards according to the color dimension (e.g., blue rabbits are sorted with the blue boat, red boats are sorted with the red rabbit), they are told to switch and sort the same cards according to another dimension (e.g., shape). It is now well established that whereas the majority of 3-year-olds continue to sort according to the preswitch rules during the postswitch phase, the majority of 4- and 5-year-olds correctly sort by the postswitch rules (for a review, see Zelazo, Müller, Frye, & Marcovitch, 2003). According to CCC theory, 3-year-olds are able to integrate a pair of if-then rules ("If the card is red, then it goes here, and if it is blue, then it goes there"), but they cannot construct an embedded, higher order if-if-then rule ("If we are playing the color game, then if the card is red it goes here, and if it is blue it goes there, but if we are playing the shape game, then if the card shows a rabbit, then it goes here, and if it shows a boat, it goes there"). As a result, 3-year-olds cannot integrate the incompatible rule pairs in a higher order rule and flexibly select the appropriate pair of rules according to situational demands. By contrast, 4-year-olds can represent and use the higher order rule and deliberately select between the two incompatible rules.

A systematic line of research by Zelazo and colleagues (2003) has demonstrated that conflict between pre- and postswitch rules is a key condition for younger children's failure on the DCCS. For example, Zelazo and colleagues (2003) found that 3-year-olds had no difficulty when they were asked to switch dimensions in a version of the DCCS that used cards with different values for the color and shape dimensions during pre- and postswitch phase (e.g., using a blue rabbit and a red boat as target cards, children were asked to sort red rabbits and blue boats by color during the preswitch, and using a green airplane and a yellow flower as target cards, children were asked to sort green flowers and yellow airplanes by shape during the postswitch). The latter findings also suggest that 3-year-olds perseverate on the basis of particular stimulus values and not the stimulus dimension (but see Hanania, 2010). Furthermore, Frye, Zelazo, and Palfai (1995) demonstrated that when 3-year-old children are asked to indicate where the cards need to be placed during the postswitch phase, they are perfectly able to do so, but will still fail to sort the cards correctly when placing them. This dissociation between children's answers to questions about the rules and their sorting behavior shows that children's behavior in a specific context is determined by relatively local considerations (e.g., how the question is asked, how they have approached the situation in the past), and that they fail to integrate the incompatible rules by embedding them to a higher order integrated rule system (but see Munakata & Yerys, 2001).

Even though CCC theory originated in the DCCS, it is not limited to performance on this task. In fact, CCC theory has been applied to a number of other rule use tasks and a variety of other tasks that are widely used with preschool children (Zelazo & Jacques, 1997). Furthermore, CCC theory also captures the transition in earlier rule use as children younger than 3 years old have been shown to be unable to sort using a single pair of rules (e.g., Zelazo & Reznick, 1991). However, even though a more complex version of the DCCS has been developed (Zelazo, 2006; Zelazo et al., 2013), CCC theory has not been extended to capture increases in cognitive complexity beyond the preschool period.

According to CCC theory, increases in complexity are due to age-related changes in reflection. The process of reflection is further developed in the level of consciousness (LOC) model (Zelazo, 2004). Essentially, the LOC model conceives of reflection as a recursive process ("re-entrant processing") by means of which the subjective experience or the contents of consciousness at one level become the contents or object of consciousness at the next higher level. Verbal labels are essential to this process because they serve as semantic descriptors of subjective experience that can be decoupled from the immediate situation and deposited and maintained in working memory. In working memory verbal labels can then keep the goal in an activated state, which, in turn, allows the child to select the appropriate action program. We use the A-not-B error to illustrate this process. As noted earlier, the A-not-B error refers to the phenomenon that 10-month-old infants search for an object at a hiding location where they have previously successfully retrieved the object

(A) and not at the location where they saw it disappear (B; see Marcovitch & Zelazo, 2009). According to the LOC model, at a lower level of consciousness hiding the object at Location B triggers a semantic description of the hiding location from semantic long-term memory. The semantic description of Location B becomes the intentional object of consciousness, “by way of which it triggers the most strongly associated action program in procedural long-term memory” (Marcovitch & Zelazo, 2009, p. 8). In the A-not-B task, the most strongly associated action program is searching at Location A (where the object has previously been found). The response in the A-not-B task, however, changes (around the age of 12 months) with reflection because now the semantic description of the location is fed back into consciousness where it can be related to a verbal label (“Location B”) that then is decoupled from the immediate subjective experience and deposited in working memory. In working memory, the verbal label can then actively maintain the correct location and select the appropriate action program.

This idea of reflection has been instantiated in a computational model, termed the hierarchical competing systems model (HCSM; Marcovitch & Zelazo, 2009). The HCSM is based on the assumption that *goal directed* action is influenced by two types of system that are in competition with each other: (1) an associative habit system that is based on previous experience, and (2) a representational system that “captures the influence of conscious reflection on behavior and develops over the course of childhood” (Marcovitch & Zelazo, 2009, p. 6). In the absence of reflection, the influence of the representational system on behavior is weak, and the habit system dominates; with the development of reflection, the representational system exerts increasing top-down control over the habit system and overrides the habit system. The HCSM model is used to derive a number of unique predictions about infants’ search behavior in the context of the A-not-B task, and as Marcovitch and Zelazo (2009) show, available data supports these predictions.

Zelazo’s structural-functional approach to EF is multifaceted and has generated a productive program of research. However, there are several studies that do suggest that 3-year-olds can, under certain circumstances, shift sorting dimensions in the DCCS (e.g., Fisher, 2011; Jordan & Morton, 2008), which would not be anticipated based on CCC theory. One line of defense for CCC theory is that shifting may either be triggered by bottom-up, associative processes or be deliberately chosen by top-down reflective processes. From a theoretical perspective, the LOC aspect of the theory is particularly problematic. It is not clear how a recursive, iterative process can lead to levels of hierarchies because recursion is simple repetition (n + 1, n + 2, and so on) that occurs at the same level of consciousness. Contents of consciousness just simply duplicate, like a reflection in an endless line of mirrors. Furthermore, the function of labels in the reflection is problematic as well. Leaving aside the empirical question whether 12-month-olds who succeed in the A-not-B task use verbal labels (and what kind of verbal labels they use), it is not clear what it would mean for verbal labels to be decoupled from subjective experience. Verbal labels refer to objects; they have meaning because they are intrinsically coupled with subjective experience. By being decoupled from experience, they lose their meaning and are reduced to *flatus vocis* (i.e., a mere breathe of sound; Vygotsky, 1934/1986). In LOC theory, verbal labels appear to be inappropriately reified; they cannot do the work LOC assigns them to do. As a result, LOC theory fails to account for the emergence of hierarchical rule systems.

In this context, it might be illuminating to juxtapose the notion of reflection used in LOC theory with Piaget’s notion of reflecting abstraction. Reflecting abstraction is an elaborative process by which children discover the structural aspects of their activity (Piaget, 1977/2001). For instance, putting marbles, one after the other, in a receptacle is an action with several structural aspects, one of which is based on the creation of a serial order, and another on the creation of a set with a growing number of elements. By becoming aware of the relations between and coordination of their actions, children abstract structure (the coordinatory or operative aspect of actions) from content, and, in turn, project this structure to a higher cognitive level. Reflecting abstraction takes as objects not subjective experiences, but actions in the world. Language is crucial to reflecting abstraction as well (Piaget, 1974/1976), but rather than being used to decouple verbal labels from experience, language is used to conceptualize actions.

Finally, the HCSM model is a dual systems model. Even though dual systems models are currently popular in psychology, the stipulation of two systems is not without problems (see Keren & Schul, 2009). For example, it is not clear that habits can be radically juxtaposed to the representational system because habits are the result of automatizing intentional actions (see Piaget, 1936/1963, for an analysis of habits). Indeed, habitual actions are mostly intentional (e.g., making coffee in the morning; see Logan, 1988; Neumann, 1984). If they were causally triggered by a stimulus, they would be a reflex, and a reflex cannot be regulated;

habits can (see Piaget, 1974/1976). Thus, the HCSM model may introduce a dichotomy where none exists.

Summary

Our review of a variety of influential theories on the development of EF suggests that there currently are no comprehensive developmental theories of EF, and the theories of EF we reviewed are fraught with conceptual problems. It is currently unclear whether EF is characterized by qualitative changes and develops in terms of a sequence of hierarchical levels, or whether it simply undergoes quantitative change (e.g., increase in inhibition, stronger activation in working memory).

A comprehensive theory of the development of EF should specify the particular organization of EF at different points in development and explain the processes that lead to the successive transformation of the organization. The developmental process should have its own logic, with biological change and social factors being necessary but not sufficient conditions of development. Most theories do not specify sufficiently the processes or factors that promote the development of EF, and we have argued that those that do provide conceptually problematic explanations. We will offer some suggestions about how to conceptualize EF development in the conclusion.

Finally, different theories of the development of EF are located at different levels of explanations. The neural network approach is located at the subpersonal level of explanation (Dick & Overton, 2010). At the subpersonal level, explanations place behavior in the context of causal connections by proposing mechanisms that produce an output given a particular input; concepts such as meaning, intentionality, or consciousness have no place at the subpersonal level. By contrast, the CCC/LOC account is located at the personal level at which explanations aim to make the behavior of the person intelligible by viewing her behavior as being guiding by norms of rationality. At the personal level, concepts such as reasons, intentionality, choice, and consciousness come into play. These levels of explanations are not necessarily incompatible. In fact, they can productively inform each other, and explanations at one level can constrain explanations at the other level. However, problems arise when one level is confounded with the other. This is the case, for example, in the statement that individual differences in the sensitivity to neural error signals may be the result of differences in "individuals' ability or propensity to reflect upon that signal" (Lyons & Zelazo, 2011, p. 390). We argue that it would be a similar category mistake to explain psychological development through neurological development. Neurological development is a necessary but not a sufficient condition for psychological development. Furthermore, psychological experience itself fosters neurological development, a topic to which we turn in the next section.

REVIEW OF EMPIRICAL RESEARCH ON THE DEVELOPMENT OF EF AND ITS NEURAL BASIS

In this section, we first review research on the development of neural systems underlying EF. Next, we summarize research on the development of inhibition, working memory, and flexibility. Our review is necessarily selective and focuses on developmental trends that children show in widely used measures of EF (for excellent reviews, see Best, Miller, & Jones, 2009; Carlson, 2005; Garon et al., 2008). Next, we examine the development of children's performance on more complex EF tasks. Finally, we review developmental research on hot EF. We acknowledge that our treatment of EF tasks as either measures of working memory, inhibition, or flexibility is too simplistic because EF tasks likely measure more than one EF component. Our coverage of particular tasks in particular sections does not reflect any theoretical commitment; rather, it reflects the way these tasks are treated in the literature.

Development of the Neural Basis Underlying EF

As noted, historically the terms *executive function* and *frontal lobe* function were considered synonymous, and while current conceptualizations of EF extend beyond this circular definition, the equivalence of these two terms has been so ubiquitous within the research literature that developmental changes on EF measures have often been considered as evidence of development of the PFC. In humans, research investigating the development of PFC and the impact on EF does present with some limitations due to the difficulty with neuroimaging "growth" and developmental change in humans and the inability to conduct true controlled experiments (see Stiles et al., Chapter 2, this *Handbook*, this volume, for a review of strengths and limitations of the different methods used to study the brain).

Anatomically, the frontal lobes, overall, are considered to be the cortex anterior to the central sulcus, and this region contains several important brain regions, including the primary motor strip, premotor and supplementary motor areas involved in planning movement, and the PFC. Within the frontal region, the PFC, including the most anterior brain regions, receives input from all regions of the frontal and posterior neocortex, and has been thought to provide the neural substrate for EF (Barbas, 1992; Fuster, 1993). According to Kolb and colleagues (2012), across mammals there is no universally acceptable definition of PFC, but it is generally regarded as the "region of the cortex that receives its principal thalamic inputs from the mediodorsal nucleus of the thalamus" (p. 17186). A great deal of knowledge about the development of the PFC is based on animal studies. In humans, the PFC is an especially large region of the brain, accounting for about one fourth of all cerebral cortex. Given the unique location of the PFC and its dense connections to sensory and multimodal association areas, cortical and subcortical motor systems, and limbic and memory systems, it is ideally suited to orchestrate behavior.

In humans, the PFC is further subdivided into various regions, including the dorsolateral PFC (DLPFC), orbitofrontal cortex (OFC), and ventromedial PFC (VMPFC). In general, the DLPFC is considered to support online processing of information and integrating different dimensions of cognition and behavior (Lezak, Howieson, & Loring, 2004). This area has been associated with various specific cognitive tasks, including working memory, verbal and design fluency, ability to maintain and shift set, and planning, response inhibition, as well as higher order skills, including organization, reasoning, problem solving, and abstract thinking (Alvarez & Emory, 2006; L. Clark et al., 2008). DLPFC has also been specifically associated with supporting working memory and goal-directed behavior and is highly involved in the temporal organization of behavior and support of cognitive functions necessary to organize behaviors both in context and in time (Goldman-Rakic, 1987; Kolb, 1984; C. R. E. Wilson, Gaffan, Browning & Baxter, 2010). The OFC has been associated with aspects of impulse control, maintenance of set, monitoring of ongoing behavior, and socially appropriate behaviors, as well as aspects of reward and emotional experience (Alvarez & Emory, 2006; Rolls & Grabenhorst, 2008). The dorsal region of the anterior cingulate cortex (ACC), a part of the limbic system, sits medial and adjacent to the DLPFC and has been noted to be involved in emotional drives, inhibition of inappropriate responses, reward processing and decision making (Alvarez & Emory, 2006; Holroyd & Coles, 2002).

As noted earlier, it was long theorized that these frontal regions were "functionally silent" in infancy and early childhood (Golden, 1981) and relatively immature in children, and that they went through a long protracted development process continuing into adolescence (Cummings, 1993; Yakovlev & Lecours, 1967). While research refutes the idea of the frontal lobes being inactive during childhood, evidence does support frontal cortices following a slower developmental trajectory than other brain regions (Casey, Giedd, & Thomas, 2000; Fuster, 2002). Like all areas of the brain, the frontal cortices undergo dendritic arborization, synaptogenesis, and myelination but the frontal regions develop last (Fuster, 1993; Huttenlocher, 1979; Huttenlocher & Dabholkar, 1997; Jernigan & Tallal, 1990; Kolb & Fantie, 1989). Indeed, there are changes in gray and white matter volume as well as cortical thickness from childhood into the third decade of life (Asato, Terwilliger, Woo, & Luna, 2010; Dosenbach et al., 2010).

Research now has provided evidence that there is very early functionality of the PFC, and this has been demonstrated even prenatally. Animal work using hamsters suggests that PFC neurons appear early in neurogenesis and migrate as part of an anterior-to-posterior projection (Kolb et al., 2012). In humans, fMRI studies assessing resting state networks have detected the existence of executive control networks in term-equivalent and preterm infants. These networks include the medial-frontal areas, including the anterior cingulate, paracingulate, and superior frontal gyrus bilaterally (Doria et al., 2010).

As in animals, it has been known for some time now that the frontal cortices are active in infancy (Bell & Fox, 1992; Chugani, Phelps, & Mazziotta, 1987; Gaillard et al., 2000), with evidence of content specific frontal activations within DLPFC (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002; Tzourio-Mazoyer et al., 2002). Likewise, it has been known that the time course for synaptic enhancement and pruning varies enormously by brain region (Huttenlocher, 1979). In the visual cortex, synaptic overproduction reaches a maximum at about 4 months, followed by synapse elimination through preschool age, reaching adult levels at about 11 years of age. The greatest density of synaptic overproduction in the PFC, and peak spine density, occur at around 5 years of age. Some densities exceed adult values by two- to threefold and only begin to decrease substantially during puberty (Petanjek et al., 2011) and on into as late as the third decade of life. Gogtay and colleagues (2004), using longitudinal sequential MRI scanning, have shown that typical development includes a shifting pattern of gray-matter loss, starting around 4 to 8 years in dorsal parietal and primary sensorimotor regions, and spreading laterally and caudally into temporal cortices and anteriorly into dorsolateral prefrontal areas. Areas with the most basic functions are first to develop; areas involved in spatial orientation and language follow around the age of puberty. Areas with more advanced functions—integrating information from the senses, reasoning and EF—develop last, in late adolescence. Within the PFC, reduction of gray matter is completed earliest in the OFC, followed by ventrolateral PFC (VLPFC) and then by DLPFC. Progression of myelination in the developing human brain shows the opposite pattern, with white matter volume increases as myelination continues well into the third decade of life, and spatial and temporal pattern paralleling developmental changes in synaptic density (Benes, Turtle, Khan, & Farol, 1994; Yakovlev & Lecours, 1967). Research using dynamic tensor imaging (DTI) has shown greater coherence of white matter tracts (increased fractional anisotropy) with age, consistent with better performance on tasks requiring interactions between brain regions (Liston et al, 2006; Nagy, Westerberg & Klingberg, 2004).

While it has been recognized for some time that this massive overproduction of synaptic density and the prolonged period of pruning the PFC allows for the optimal development of the complex brain circuitry adaptive to an individual's environment, what has become clearer is the significant modification of this circuitry that occurs through early life experiences. Indeed, early experiences (negative or positive) can influence PFC trajectories that have lifelong consequences on behavioral regulation. There is also considerable evidence that prenatal and early life experiences modify this prenatal circuitry (Petanjek & Kostović, 2012; for a thorough review see Mackey, Raizada, & Bunge, 2013).

It has long been understood that while frontal cortices and PFC are crucial for EF, these regions of the brain are not solely responsible for behavior, though it is typically assumed that the PFC does participate in EF (Alvarez & Emory, 2006; Kane & Engle, 2002). Current conceptualizations of and research addressing the development and neural basis of EF, however, stress the importance of brain networks and systems as being key in understanding EF, especially as it relates to the human ability to regulate and modulate behavior to achieve goal states. Morton (2010, p. 712) states,

> There is growing evidence that complex cognitive operations that support EF are not localized in lateral PFC, but are distributed over a network of regions, including anterior cingulate, lateral prefrontal, medial prefrontal, and posterior parietal cortices, as well as subcortical structures such as the basal ganglia and thalamus, with the organization of this network changing dramatically over development.

While traditionally brain networks have been acknowledged (Casey, 2001), current conceptualizations have greatly extended the importance of connectivity patterns within networks for cognitive development.

As noted earlier, fMRI data is being increasingly used to study functional connectivity and to assess brain networks. *Functional connectivity* can be assessed through numerous correlative data analytic approaches developed to quantify the interrelations of signal changes in distal brain regions (Friston, 2002). Strongly correlated patterns of neural activity displayed across distributed brain regions evidence their functional connectedness (Fingelkurts & Kahkonen, 2005; for a detailed review see Stevens, 2009). Different researchers have identified various networks in this manner. Cole and colleagues (Cole & Schneider, 2007; Cole, Pathak, & Schneider, 2010) identified the default mode network, a resting state network that is based on the pattern of brain activity when the person is not performing a task, and the cognitive control network, which includes frontal regions (e.g., DLPFC, ACC, and anterior insular cortex, etc.) that are coactivated when a person is performing cognitively demanding tasks. Fair, Dosenbach, Church, Cohen, and Brahmbhatt (2007) have identified distinct fronto-parietal and cingulo-opercular networks that also appear to be involved in aspects of cognitive control. In general, these functional connectivity studies are providing some level of replication of findings, in that networks that are responsible for aspects of cognitive control and EF seem to change with age, generally moving from networks that are anatomically local to a more distributed organization with increasing age (Ezekiel, Bosma, & Morton, 2013; Fair et al., 2009; Stevens, Kiehl, Pearlson, & Calhoun, 2007). The development of these brain networks is hypothesized to occur as a process whereby networks that are initially more "localized" (within the same brain region) become more distributed as the child ages and the underlying abilities develop. Indeed, it is suggested that in younger children, performance on EF tasks may rely on different regions, and, as children develop, more adult-like networks are established (Jacobs, Harvey, & Anderson, 2011). Edin and colleagues (2007) found that the strengthening of these connections could be accounted for by the strengthening of synaptic connectivity between different regions, but not by pruning and myelination.

Further support for the utility of a functional connectivity approach to understanding the development of EF comes from studies of young children with damage to the frontal regions of the brain (see Pennington, Chapter 23, this *Handbook*, this volume). Jacobs and colleagues (2011) compared the performance of children, aged 7 to 16 years, with radiological evidence of frontal pathology ($n = 38$), extra-frontal pathology ($n = 20$), generalized pathology ($n = 21$) and healthy controls ($n = 40$). Groups were compared on a range of EF domains, including attentional control, goal setting, and cognitive flexibility. Contrary to expectations, based on adult lesion-based studies, there was little differentiation in executive processes between frontal and extra-frontal groups. In comparison to controls, children with cerebral pathology, irrespective of the site of damage, exhibited deficits on the EF domains assessed. The authors interpreted these results as calling into question the localized nature of executive skills in childhood, and providing support for a distributed, but integrated neural network for such skills, arguing that the entire brain is necessary for adequate EF in childhood. The findings also suggested that focal damage to any brain region during development could render a child at risk for a range of executive deficits, something that is unlikely to occur in the adult brain. This is consistent with findings from animal work suggesting that extra-frontal damage early in life may also disrupt ongoing development of the PFC and lead to changes in prefrontal morphology and function (Bertolino et al., 1997). Eslinger, Flaherty-Craig, and Benton (2004) described 10 cases of early PFC damage from the clinical literature, including evidence of brain regions affected, clinical profiles, and functional developmental outcomes. The findings were interpreted as evidence for the indispensable role of the PFC in psychological development from early childhood into adulthood. Most of the cases demonstrated chronic, profound impairments in social cognition, learning from experience, and emotional and social deficits, with characteristic impairments in moral behavior and empathy, and cognitive impairments in attention, self-regulation, inhibition, planning, organization, working memory and self-awareness/self-monitoring, anticipation of consequences, and goal-directed behavior. In almost all, these impairments severely limited the individuals' abilities to successfully participate in school; form sustained or reciprocal relationships with their families, peers, or communities; live independently; maintain jobs; and benefit from their experiences.

Clinical case studies suggest distinct developmental differences after dorsolateral, mesial, and orbital-polar prefrontal lesions. Case JC (Eslinger & Biddle, 2000) provides a clear example of developmental right DLPFC damage, resulting in visuospatial and attentional impairments without significant emotional, personality, or behavior problems. Case SC2 (Daigneault, Braun, & Montes, 1997) provides a striking example of developmental mesial frontal impairment with deep white matter disconnection leading to profound loss of initiative and motivation as well as inattention and emotional dependency. Early orbital and polar prefrontal cases constitute the most challenging cases, with intractable deficits in self-regulation, emotion, and EF that are severely disabling and resistant to treatment efforts. These distinctive outcomes after damage to dorsolateral, mesial, and orbito-polar prefrontal regions are similar in many respects to those reported after acquired injury in adulthood (Eslinger & Geder, 2000).

More profound deficits are usually seen after unilateral or bilateral damage to the frontal poles and/or the orbital and inferior mesial prefrontal regions, regardless of age of onset. The effects of early PFC damage must also be viewed not as the result of isolated areas of damage but as affecting the strong and essential interactions among diverse frontal lobe regions and thalamic, basal ganglia, limbic, and posterior cortical systems. Such multisystem disruption has the potential to affect the development of interacting areas that mediate the acquisition of representational knowledge, actions, and response control through contingency learning. Drawing on Piagetian models, Eslinger and colleagues (2004) suggest that an early and prominent developmental role for the PFC would be in "organizing and integrating rather disparate and seemingly elusive information about ourselves, others and the world into more consistent rules, guidelines and mental conceptions that allow increasing flexibility to elaborate knowledge and experiences" (p. 101). The authors conclude that rather than a single underlying deficit associated with early PFC damage, it is the altered integration and interplay of cognitive, emotional, self-regulatory, and executive/metacognitive deficits that contribute to diverse developmental frontal lobe syndromes. They emphasize the fundamental importance of PFC development in protracted cognitive, social-emotional, and moral development. While they provided a detailed analysis of case studies in which there was clear evidence of prefrontal pathology, it is not clear from these studies whether lesions to other brain regions can, in and of themselves, result in executive impairments in childhood.

Development of Working Memory

A basic distinction within WM research is between a short-term storage system that maintains information over a delay (corresponding to Baddeley's [2012] visuospatial sketchpad and phonological loop) and a system that, in addition, manipulates information (corresponding to Baddeley's central executive). It is sometimes only the latter system that is considered to be a component of EF. Numerous tasks have been developed that assess the different components of working memory in infants, children, and adolescents (see Best & Miller, 2010; Carlson, 2005; Garon et al., 2008). Here we provide a brief review of the development of the different components and their underlying neurological substrate.

The ability to hold information over time emerges in the first year of life. A widely used task to assess visuospatial short-term memory is the delayed response task (Hunter, 1913; Pelphrey & Reznick, 2003). This task involves the hiding of one or more objects in two or more locations (see Pelphrey & Reznick, 2003). After a delay, infants must recall the location where the object was hidden (e.g., by manually retrieving the object). Multiple trials are administered during which the hiding location of the object is varied. Research by Pelphrey and colleagues (2004) has shown that in the second half of the first year of life infants tolerate increasingly longer delays and succeed in finding the object among an increasing number of hiding locations.

Forward digit and word span tasks are often used to investigate the development of the phonological loop. For example, in the forward digit span task children are presented with spoken sequences of digits or words and they have to recall the items in the correct serial order; list length is increased when children recall a certain number of lists at a particular length correctly (Gathercole et al., 2004). The block recall task, or spatial span, is another measure to assess visuospatial memory. In this task, children are presented with an increasing number of blocks and are asked to reproduce the order in which the experimenter taps the blocks (Gathercole et al., 2004). Backward span tasks are often used to assess the central executive; in these tasks children must recall the sequence of items in the reverse order (Carlson, 2005). Another measure of the central executive is the listening recall task; in this task, children listen to short sentences, one at a time, judge whether each sentence is true, and recall the last word of each sentence in sequence. The number of sentences is gradually increased (Gathercole et al., 2004).

Children's performance on tasks that measure the visuospatial sketchpad, phonological loop, and central executive linearly increases between the ages of 4 to 15 years (Alloway & Alloway, 2013; Gathercole et al., 2004). Children succeed later on backward span tasks, which require the maintenance and manipulation of information, than on forward span tasks, which require only the maintenance of information (e.g., Carlson, 2005). The former type of task also shows a more protracted development (Conklin, Luciana, Hooper, & Yarger, 2007; Tulsky, Carlozzi, Chevalier, Espy, Beaumont, & Mungas, 2013). Working memory tasks that require the use of self-generated search such as the self-ordered search task likewise show systematic improvements with age (Archibald & Kerns, 1999). In one version of the self-ordered search task, different-colored boxes were presented on a computer screen representing locations that participants needed to search to find blue tokens. Each box contained one token, and participants needed to remember which boxes they had already sampled to avoid a search error. Difficulty levels were systematically increased by adding boxes (Conklin et al., 2007). In order to avoid errors, participants needed to generate a strategy to organize their search and continuously update information, which arguably required a high level of executive control. Conklin and colleagues (2007; see also Luciana, Conklin, Hooper & Yarger, 2005) found that the number of errors for more difficult trials (i.e., six and eight boxes) significantly decreased between the ages of 9 to 10 years and 13 to 15 years, and strategy use increased significantly across the whole age period tested (i.e., 9 to 17 years), suggesting that working memory functions that involve a high level of executive control display a particularly protracted development.

Confirmatory factor analyses show that the phonological loop, visuospatial sketchpad, and central executive are differentiated in 6-year-olds, and that the structure of working memory does not change between 6 and 15 years. However, in preschool children the central executive may not yet be differentiated from the visuospatial sketchpad and phonological loop (Alloway, Pickering, & Gathercole, 2006; Schmid et al., 2008). Furthermore, in children the central executive is more strongly correlated with the visuospatial sketchpad and the phonological loop than the latter two components are with each other, suggesting that the visuospatial and verbal system are separable in childhood (as they are in adults), and that the central executive is responsible for coordinating the flow of information through the working memory systems (Gathercole et al., 2004; Schmid et al., 2008).

Developmental change in working memory has been linked to a number of different factors, including increase in processing speed, change in strategy use, and use of verbal rehearsal (see, for example, Barrouillet & Calmos, 2011; Fry & Hale, 2000; Gathercole et al., 2004). Increases in processing speed may speed up verbal rehearsal and thus improve the maintenance of information in verbal working memory. Indeed, studies have shown that increases in verbal working memory span can be predicted from speed in word repetition (e.g., Fry & Hale, 2000), and that when speed of word repetition was controlled, differences in verbal memory span between children and adults were no longer significantly different (Case, Kurland, & Goldberg, 1982). Higher processing speed could also lead to a more efficient use of attentional control processes, which would then free up resources that could be allocated to refreshing representations in working memory (Barrouillet, Bernardin, & Camos, 2004).

Effective organizational strategies such as semantic categorization of information (Schelble, Therriault, & Miller, 2012) and verbal rehearsal may also contribute to improvements in verbal short-term memory. Children under the age of 6 years show little evidence of verbal rehearsal (e.g., Henry, Messer, Luger-Klein, & Crane, 2012; Lehmann & Hasselhorn, 2007), and the gradual increase in the tendency to rehearse information to be recalled may result in better verbal working memory (but see Jarrold & Hall, 2013).

Functional MRI suggests that children recruit the same frontoparietal network in visuospatial working memory tasks as adults, but older children show stronger and more focal activation in these regions than younger children (e.g., Darki & Klingberg, 2014; Klingberg et al., 2002; see Stiles et al., Chapter 2, this *Handbook*, this volume). Similarly, connectivity analysis of activation during a verbal working memory task revealed that the majority of functional brain networks involved in verbal working memory showed strong functional connectivity already in children (9- to 12-year-olds), and functional connectivity did not differ between children, young adolescents (13- to 16-year-olds) and older adolescents (17- to 19-year-olds; van den Bosch et al., 2014).

The distinction between maintenance and manipulation of information in working memory is consistent with findings from fMRI studies: simple storage tasks involve VLPFC, and tasks that require the manipulation of information involve the DLPFC (e.g., Barbey, Koenigs, & Grafman, 2013). Isolating maintenance and manipulation demands of working memory tasks, Crone and colleagues (2006) found that 8- to 12-year-old children showed a similar activation of VLPFC as adolescents (13–17 years) and adults on maintenance trials, but unlike adolescents and adults children failed to recruit DLPFC and bilateral parietal cortex on manipulation trials. Furthermore, activation in right DLPFC and bilateral superior parietal cortex but not in left VLPFC was associated with performance on the manipulation task (but see Jolles, Kleibeuker, Rombouts, & Crone, 2011). A follow-up study by Jolles and colleagues (2011) showed that age-related increases in right DLPFC activation in the manipulation relative to the maintenance condition were specific to the manipulation of information and could not be attributed to general task difficulty (e.g., increased memory load).

To summarize, empirical studies support the idea that working memory becomes more fractionated and neurologically localized with advancing age. Furthermore, manipulation of information emerges later and shows a more protracted time course than maintenance of information.

Development of Inhibition

As mentioned earlier, inhibition is a multifaceted construct as reflected in different taxonomies of inhibitory processes. In this section, we chart the development of response inhibition and interference control, describe in this process a number of widely used measures of these aspects of inhibition, and discuss the neural substrate of inhibitory processes.

Response inhibition is assessed by tasks that require that a dominant, prepotent or automatic response be withheld (restraint inhibition), delayed (delay inhibition), down-regulated, or stopped (cancellation; see Sinopoli, Schachar, & Dennis, 2011). In its most simple instantiation, restraint inhibition consists of stopping a particular motor action in order to comply with commands of the caregiver, a behavior that emerges at the end of the first year of life (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996; Kopp, 1982). For young children, a variety of tasks have been designed to assess the downregulation of motor activity (i.e., intentional slowing of movements, lowering of voice; see Kochanska et al., 1996). For example, children's ability to lower their voice is assessed with the Whisper task, in which children are asked to whisper the names of cartoon characters depicted on cards. Performance on this improves gradually between 3 and 6 years of age (Carlson, 2005).

The go/no-go task is widely used to investigate response inhibition in children. This task can take a variety of different forms which have in common that they require participants to make a binary choice between responding to one stimulus and refraining from responding to a different stimulus (Luria, 1961). Some go/no-go tasks used with preschool children are modeled on the children's game "Simon says" (Carlson, 2005). For example, in the

Bear-Dragon task, children are asked to perform an action (e.g., touch their nose) in response to commands of a "nice" bear puppet, but refrain from performing an action in response to commands of a "naughty" dragon puppet. Performance on the Bear-Dragon task improves rapidly between 3 and 4 years and reaches ceiling in 5- to 6-year-olds (Carlson, 2005; Jones, Rothbart, & Posner, 2003).

Whereas the prepotency in the Bear-Dragon task is pre-existing (assuming that children have a habitual tendency to respond to commands), prepotency in other versions of go/no-go tasks are created by presenting go-trials more frequently than no-go trials. Empirical evidence with respect to age-related changes and when children reach adult performance on no-go trials is inconsistent (e.g., Archibald & Kerns, 1999; Becker, Isaac, & Hynd, 1987; Brocki & Bohlin, 2004; Johnstone et al., 2007; Müller, Kerns, & Konkin, 2012). There are a variety of factors that might explain these inconsistent findings, including the amount of time children are given to respond (Simpson & Riggs, 2006) and the frequency of no-go trials (Berwid et al., 2005). An interesting variation of the go/no-go task was created by Cragg and Nation (2008) to investigate whether a slow inhibitory process in younger children is responsible for their inability to suppress a response to no-go trials. Children were asked to hold down the home key with their index finger between trials, to release this key to press another key on go trials, and to continue pressing the home key during no-go trials. In this manner, Cragg and Nation could capture whether children partially inhibited the no-go response (i.e., released the home key but stopped the movement before pressing the target key). Partial inhibition occurred on 41% and 34% of the trials for 5- to 7-year-olds and 9- to 11-year-olds, respectively, and there was a significant trend for partial inhibitions to decrease and successful inhibitions to increase with age. Thus, older children were more able to hold the response at an earlier stage (before it was initiated) than younger children, supporting the suggestion that response inhibition becomes faster during childhood.

Whereas go/no-go tasks require the inhibition of a response when it is being prepared, in the Stop-Signal task children need to cancel a response that has already been started. In the Stop-Signal task, participants perform a primary visual binary choice reaction time task and on a portion of trials are required to inhibit that response if presented with a Stop-Signal (auditory or visual stimulus; Logan, Cowan, & Davis, 1984) on that trial. The interval between the onset of the primary task stimulus and the Stop-Signal can be systematically varied, affecting inhibition success. The Stop-Signal task is based on a mathematical race model of whether the "go" processes reach completion before the inhibitory process, used to derive an estimate of the latency of the inhibitory process (Stop-Signal Reaction time, SSRT). Studies generally show that stopping improves during childhood (e.g., Carver, Livesey, & Charles, 2001; Williams, Ponesse, Schachar, Logan, & Tannock, 1999), although findings are not always consistent (Band, van der Molen, Overtoom, & Verbaten, 2000). Improvement in the Stop-Signal task has been attributed to increased efficiency of the inhibitory process (i.e., the inhibitory process becomes faster and reaches completion before the go process, see Carver et al., 2001).

Interference control has been defined as the "ability to suppress a dominant response related to perceptual stimuli in the task while selecting and executing a competing, conflicting subdominant response" (Montgomery & Koeltzow, 2010, p. 308). The Stroop test is a prototypical interference control task because word reading is automatic and therefore interferes with color naming. Reduced error rates and faster response times on the Stroop test reflect better interference control. Developmental studies have shown improvements in performance on the Stroop test from middle childhood to adolescence (e.g., Bub et al., 2006; Huizinga et al., 2006).

To measure interference control in children who cannot read, a number of Stroop-like tasks have been designed. These tasks have in common that they require children to resolve some sort of conflict—which is why these tasks are considered measures of conflict inhibition (Carlson & Moses, 2001)—but they vary widely in terms of response modality (e.g., manual, verbal), stimulus complexity (i.e., whether stimuli are unidimensional [e.g., shape] or multidimensional [e.g., shape, color, size]), and thus the type and degree of conflict.

A relatively simple interference task, mastered by the majority of 2-year-olds, is the Shape Stroop (Carlson, 2005; Kochanska, Murray, & Harlan, 2000). In this task, children are shown picture cards on which small fruit (e.g., apple) are embedded in a drawing of a large, different fruit (e.g., banana). Children's task is to point to the little fruit. The most widely used Stroop-like task with preschoolers is the Day–Night task (Gerstadt, Hong, & Diamond, 1994). In the original version of this task, children are required to say "night" in response to a picture of a sun, and "day" in response to a picture of a moon. Children's performance on the Day-Night task improves relatively gradually between the ages of 3 and 7 years (Montgomery & Koeltzow, 2010).

The Day-Night task and its variants (e.g., Archibald & Kerns, 1999; Macdonald, Beauchamp, Crigan, & Anderson, 2014) share with the original Stroop test the requirements that (a) task instructions must be maintained over a series of trials, (b) a dominant response associated with the perceptual stimuli must be suppressed, and (c) a conflicting, subdominant response must be activated (Montgomery & Koeltzow, 2010). However, in contrast to the original Stroop test, in the Day-Night task children cannot ignore the perceptual information and must attend to the picture cards as they specify the correct response (Montgomery & Koeltzow, 2010). Another difference between the Day-Night task and the Stroop test is that in the Day Night task the conflict is not generated by two dimensions intrinsic to the perceptual stimuli (see Algom, Chajut, & Lev, 2004, for an analysis of the logical structure of Stroop stimuli).

Systematic task manipulations have clarified the factors that affect performance on the Day-Night task (Diamond, Kirkham, & Amso, 2002; Montgomery & Koeltzow, 2010; Simpson, Riggs, Beck, Gorniak, Wu, Abbott, & Diamond, 2012). One critical feature that makes the Day-Night task difficult is that the actual name of the object on the picture belongs to the response set, regardless of whether the stimulus is semantically related to the response. For example, 4-year-olds perform poorly on the Day-Night task when they are instructed to say “book” to the picture of a car and “car” to the picture of a book (same response set, no semantic relation), and their performance is significantly better when they are instructed to say “cat” to a picture of a dog and “foot” to a picture of a hand (different response set, semantic relation; Simpson et al., 2012). One explanation of the response set effect is that the overlap between stimuli and responses increases the prepotency of the incorrect response because the correct response on one trial (e.g., “book” to a picture of a car) is the incorrect response on the next trial (say “car” to a picture of a book), and the incorrect but prepotent response on one trial (e.g., “car” to a picture of a car) becomes the correct response on the next trial (“car” to a picture of a book). Thus, the response set effect may be caused by trial-to-trial carryover effects (positive and negative priming; Montgomery & Koeltzow, 2010). According to this interpretation, the finding that imposing a delay between stimulus presentation and response improves performance is due to the dissipation of interference and a decline in the activation of the incorrect response (Simpson et al., 2012).

Similar to the Stroop test, the Flanker task requires children to ignore irrelevant and conflicting stimulus information (Eriksen & Eriksen, 1974). In the original Flanker task, participants must identify as quickly as possible a target item that is defined by its location and flanked by irrelevant stimuli on either side. On congruent trials, these flankers activate the same response as the target item (e.g., two Ss on each side of a target S); on incongruent trials flankers activate the incorrect response (e.g., Hs on each side of the target S). A child version using a fish facing to the right (or left), presented at the fixation point on a computer screen requires children to ignore flanker fish either pointing in the same or opposite direction (see Rueda et al., 2004). On incongruent trials accuracy and reaction time is worse than on congruent trials, due to the additional attentional processing caused by the interference (e.g., McDermott, Pérez-Edgar, & Fox, 2007; Rueda et al., 2004). Younger children (i.e., 5- to 10-year-olds) are significantly more impacted by incongruent flanker than adolescents and adults (e.g., Huizinga et al., 2006).

Age-related improvements in performance on interference control tasks have been attributed to a number of sources including developmental changes in the efficiency of an independent inhibitory processes, changes in working memory, and changes in processing speed (Diamond, 2013; Montgomery & Koeltzow, 2010; McAuley, Christ, & White, 2011). Factor-analysis, correlational and regression methods as well as experimental approaches have been employed to investigate the relations between working memory and inhibition. Findings from factor-analytic and correlational approaches are inconsistent, with studies suggesting that (a) working memory and inhibition are interdependent in early childhood and only become separable in middle childhood (Tsujimoto, Kuwajima, & Sawaguchi, 2007) or adolescence (Shing, Lindenberger, Diamond, Li, & Davidson, 2010); (b) working memory and inhibition are separable already early in childhood (e.g., Miller et al., 2012; Urben et al., 2011); and (c) working memory and inhibition become better integrated with age (Roncadin, Pascual-Leone, Rich, & Dennis, 2007). The extent to which inconsistent findings reflect (age-related) differences in the relation between different aspects of inhibition and working memory needs to be more systematically investigated. A longitudinal study by Luna, Garver, Urban, Lazar, and Sweeney (2004) found that processing speed did not predict variance in inhibition, and although working memory maintenance predicted a significant amount of variance in inhibition, the amount of variance was small (2%), suggesting that working memory and inhibition are largely independent processes. Experimental manipulations of task features also support the position that inhibition cannot be reduced to processing speed and working memory (e.g., Beveridge et al., 2002; Wright & Diamond, 2014).

Developmental changes in performance on measures of inhibition coincide with changes in brain activity. In a longitudinal study (9-year-olds were assessed again as 11-year-olds), Durston and colleagues (2006) observed decreased activation on no-go trials in DLPFC, but increased activation in task-relevant ventral PFC, a pattern of change that was conceptualized as a shift from diffuse to more focal activation. Hwang, Velanova, and Luna (2010) conducted an fMRI study with 8- to 12-year-old children, 13–17-year-old adolescents, and adults, measuring the directionality of subcortical-cortical connectivity while participants performed an inhibitory control task (i.e., anti-saccade task). Connectivity in children was characterized by strong short-range connectivity within parietal cortex and little top-down (frontal to parietal and subcortical regions) connectivity. There was evidence for increased top-down connectivity and decreased short-range parietal connectivity in adolescence, with further development of top-down connectivity from adolescence to adulthood. According to Hwang and colleagues (2010), these findings suggest that development of inhibitory control is characterized by the "engagement of more distributed networks that act in a collaborative manner to support top-down executive control of behavior" (p. 1543).

To summarize, qualitative changes in different aspects of inhibition over the first 6 years of life are followed by more gradual changes that, at least on some measures of inhibition, extend into adolescence and adulthood. It is unclear whether later changes in inhibition are mostly quantitative (e.g., decreases in reaction time) or reflect qualitative changes as well (e.g., use of different strategies). Little is known about the dimensionality and the relations between different aspects of inhibition at different ages, and more longitudinal studies are necessary to clarify the relations between inhibition, working memory, and processing speed.

Development of Flexibility

Flexibility—often also referred to as shifting or set shifting—is a polysemous concept (Ionescu, 2012). Generally, it refers to the ability to shift between responses, attributes of stimuli, sets, strategies, or tasks in an adaptive manner, and it presupposes the understanding that there are at least two possible ways of acting or perspectives in a given situation (Diamond, 2013). It has been claimed that flexibility is a relatively late emerging EF because successful shifting is assumed to presuppose a particular level of working memory (i.e., holding rules in mind) and inhibition (i.e., inhibition of the task or set that participants switch from; Diamond, 2013; Garon et al., 2008; Jacques & Marcovitch, 2010). CFA studies with preschoolers have not identified a separate flexibility factor, perhaps due to poor measures of flexibility. Furthermore, Ionescu (2012) suggested that flexibility is not a skill or ability but rather a property of the cognitive system that emerges from the interplay of multiple processes (for a similar view see Cragg & Chevalier, 2012; Ezekiel et al., 2013). We return to this issue after charting the developmental course of flexibility, using a number of tasks that have been created to assess flexibility (for an excellent review, see Cragg & Chevalier, 2012).

Flexibility has been studied extensively in the context of children's categorization and sorting behaviors. At around 24 months, children are able to shift between types of objects (e.g., red block into pile A, blue block into pile B, red block into pile A, etc.) when constructing an exhaustive, spatially defined grouping by object type (Sugarman, 1983). This kind of sorting behavior suggests that they can judge an object as not belonging to one group (A), and still consider it as a possible member of another group (B): What is not like A is or may be like B (Sugarman, 1983).

Inductive categorization tasks assess children's flexible reclassification of objects. Children are given several objects that can be grouped on the basis of different dimensions (e.g., color, shape, size). Once children have grouped the objects on the basis of a shared feature, they are asked to produce further groupings based on different features. Using this paradigm, Smidts, Jacobs, and Anderson (2004) found that 42% of the 5-year-olds, 60% of the 6-year-olds, and 90% of the 7-year-olds produced a second grouping, while none of the 3- and 4-year-olds was able to do so. When they received specific instructions (e.g., "Put the red ones in one pile and yellow ones in a different pile," if the previous grouping had been based on size), 3- and 4-year-olds were able to produce only a second grouping, but no third grouping. Blaye, Bernard-Peyron, Paour, and Bonthoux (2006) found that the number of children who produced two or more groupings (response flexibility) increased from 37% at 5 years to 67% at 9 years. Interestingly, only 7% of the 5-year-olds but 60% of the 9-year-olds could correctly label two or more sorts (conceptual flexibility). Blaye and colleagues attribute the development of conceptual flexibility to advances in children's conceptual understanding.

Rule-use tasks are another widely used method to investigate flexibility (Zelazo & Jacques, 1997). Rule use tasks typically consist of two phases (Garon et al., 2008). In the first phase (preswitch) a set is established (e.g., children are instructed to sort cards by shape), and in the second phase (postswitch) children are instructed to shift to a different set (e.g., sort by color) that conflicts with the first set. In contrast to inductive categorization tasks, in rule use tasks the experimenter instructs children what stimulus attributes are relevant in the postswitch phase (e.g., sort by color; Jacques & Zelazo, 2005).

Rule use tasks vary considerably in terms of rule complexity, stimulus complexity, and degree of conflict (Cragg & Chevalier, 2012). In CCC theory (Zelazo et al., 2003) the complexity of rule use tasks is ordered on the basis of their level of embedding. However, the way in which other factors such as stimulus features affect complexity of rule use tasks may not be captured by level of embedding (e.g., Jordan & Morton, 2008). At any rate, there is no generally agreed-upon metric for ordering rule use tasks along a single dimension.

There are remarkable changes in performance on rule use tasks during the preschool period. Three-year-olds perform well on the *same-silly* task in which they are required to sort picture cards during the preswitch in a way that they match in shape with their target cards (e.g., place a picture card of a dog in a box indicated by a dog, and a picture card of an airplane in a box marked by an airplane) and during the postswitch to reverse their sorting (place a picture card of a dog with an airplane, place a picture card of an airplane with a dog; see Perner & Lang, 2002). Around the age of 4 years, children pass the standard DCCS, but only about one-fourth of 6-year-olds pass a version of the DCCS that requires the rapid shifting between color and shape conditional on contextual cues (i.e., black border versus no black border on test cards; Henning, Spinath, & Aschersleben, 2011).

There is considerable controversy over why children fail the DCCS. According to an influential explanation, 3-year-old children perseverate on the DCCS because they fail to inhibit attention to the values of the dimension that were relevant during the preswitch phase (Kirkham, Cruess, & Diamond, 2003). If 3-year-old children fail the DCCS for this reason, they should do well on a version of the DCCS in which the values of the preswitch dimension are removed after the preswitch phase. For example, asking children to sort red rabbits and blue boats according to shape in the preswitch phase, and to sort red flowers and blue cars according to color in the postswitch phase, removes the demand to inhibit attention to the values of the preswitch dimension because it is no longer possible to sort by these values. A number of studies (Müller, Dick, Gela, Overton, & Zelazo, 2006; Zelazo et al., 2013, Experiments 8 and 9) have shown that 3-year-olds perform equally poorly on the Standard version and this new version of the DCCS (termed *Negative Priming version*). At the same time, 3-year-olds performed significantly better on a version of the DCCS in which the values of both dimensions were changed between pre- and postswitch than on the Negative Priming version (Zelazo et al., 2003, Experiments 8 and 9), so it seems likely that they failed the Negative Priming version because of difficulty engaging attention to specific stimulus values rather than because they got stuck on the preswitch sorting dimension (e.g., color). These findings suggest that one reason of children's failure in the DCCS is that they have difficulty engaging (disinhibiting) attention to something they have previously ignored (see also Chevalier & Blaye, 2008).

Another explanation of perseveration on the DCCS is that children lack the ability to maintain the postswitch rules (goal neglect). To examine this possibility, Marcovitch, Boseovski, and Knapp (2007) manipulated the amount of conflict by administering during the postswitch phase either a high proportion of conflict cards (i.e., test cards that were mismatched with the target cards on one dimension) or a high proportion of redundant test cards (i.e., test cards that were identical to the target cards). The rationale for this manipulation was that whereas conflict would keep the rules active in working memory, redundant test cards would lead to goal neglect. Consistent with this prediction, 4- and 5-year-olds' performance in the low-conflict (i.e., redundant test cards) version was significantly worse than that in the high-conflict version, indicating that maintenance of the sorting rule in working memory plays an important role in the DCCS (see also Chevalier & Blaye, 2008).

The task-switching paradigm is frequently used to investigate flexibility in older children and adolescents. Participants are presented with two or more simple tasks and are asked to switch back and forth between these tasks. Bivalent stimuli (e.g., colored shapes) are typically used to represent the relevant properties of both tasks (e.g., task 1: judge stimulus color; task 2: judge stimulus shape). Single-task blocks (i.e., only one task must be performed) alternate with mixed-task blocks (i.e., participants must alternate between the tasks from trial to trial). Whether participants must switch in the mixed blocks is either indicated by an instructional cue or determined on the basis of a predictable sequence (e.g., task A, task B, task B, task A, task B, and so on). Two types of switch costs are distinguished in the task-switching paradigm. General switch costs are calculated by subtracting the performance (accuracy and reaction time) in the single-task blocks from the performance in the mixed-task blocks. Specific switch costs refer to the difference in performance between repeat trials and switch trials within the mixed-task block. Whereas general switch costs measure the ability to maintain and select task sets in working memory, specific switch costs measure the ability to shift flexibly between task sets (Monsell, 2003). A number of studies have examined the developmental trajectory for specific and global switch costs. Even though most studies find that switch costs are disproportionately larger for children than adults (e.g., Cepeda, Kramer, Gonzalez de Sather, 2001; Huizinga et al., 2006), findings are not entirely consistent (Davidson, Amso, Anderson, & Diamond, 2006), likely due to methodological differences. Karbach and Kray (2007) obtained larger general switch costs on accuracy and reaction time for 5-year-olds as compared to 9-year-olds, but there were no age differences in specific switch costs, indicating that task set selection and task set switching follow a different developmental course and are separable aspects of task switching performance in childhood (see also Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004), an interpretation that is backed up by fMRI studies (e.g., Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006).

On the neurological level, age-related increases in flexibility are associated with changes in the pattern and temporal dynamics of brain activity. Moriguchi and Hiraki (2009, 2011) used near infrared spectroscopy (NIRS) to examine the neural basis for preschool children's performance on the DCCS. They found that recruitment of the VLPFC during the pre- and postswitch trials increased with age and distinguished children who passed the DCCS from those who did not. Furthermore, comparing 5- to 6-year-old children's and adults' performance on the standard and a more complex version of the DCCS, Moriguchi and Hiraki (2014) discovered that adults activated VLPFC bilaterally on both tasks, and that children showed stronger activation of the left inferior PFC and weaker activation of the right PFC on the more complex DCCS version but not on the standard version. In an fMRI study, Morton, Bosma, and Ansari (2009) observed activation in the superior parietal cortex, DLPFC, inferior junction, and supplementary motor regions during a task-switching version of the DCCS. Subsequent connectivity analysis (Ezekiel et al., 2013) showed that compared to children, in adults lateral PFC was more strongly connected with the anterior cingulate, inferior parietal cortex, and the ventral tegmental area, suggesting that lateral PFC is part of a cognitive control network that becomes better integrated with age. Weaker connectivity within this network may affect the temporal dynamics of control processes in shifting tasks (see Wendelken, Munakata, Baym, Souza, & Bunge, 2012). The better integration of the cognitive control network does not preclude the possibility that different components of the network make specific contributions to shifting (e.g., updating, rule maintenance, shielding off interference). Ezekiel and colleagues (2013) conclude that "higher-order cognitive operations, such as switching in the DCCS, are likely emergent products of rapid bidirectional interactions among many functionally specialized brain regions rather than irreducible operations linked to activity in one circumscribed area alone" (p. 48).

To summarize, performance on inductive categorization and rule use tasks shows significant age-related changes that are particularly pronounced during the preschool period. Because relatively few studies have examined flexibility in middle childhood and adolescence, less is known about developmental changes during this period. A variety of processes contribute to flexibility, including the activation of a previously irrelevant task set, suppression of a previously relevant task goal, and goal maintenance (for further processes, see Cragg & Chevalier, 2012). Overall, flexibility may thus best be conceptualized as an emergent property resulting from the dynamic interplay of a multiple processes (Ionescu, 2012).

The Development of Performance on Complex EF Tasks

In this section, we briefly discuss the developmental trajectory of performance on the Wisconsin Card Sorting Test (WCST) and the Tower of Hanoi (ToH), as well as its variant, the Tower of London (ToL). The WCST and the ToH have been labeled complex EF tasks because they tap into numerous executive and nonexecutive processes, and, as a result, the source of poor performance on these tasks is difficult to determine (Miyake et al., 2000). Still, both tasks are widely used, particularly in clinical neuropsychology, and the WCST has been referred to as "the prototypical EF task in neuropsychology" (Pennington & Ozonoff, 1996, p. 55).

In the WCST, participants are presented with target cards that differ on various dimensions (e.g., color, shape, and number), and then shown individual test cards that match different target cards on different dimensions. Participants must determine the rule according to which each card must be sorted, and are informed by the experimenter after each card whether the sorting is right or wrong. After a certain number of consecutive correct responses, the target dimension is switched (e.g., from color to shape), and participants must discover this new sorting rule (Grant & Berg, 1948). Patients with lesions to the PFC typically perseverate on the WCST and continue to sort according to the initial sorting dimension after the sorting rule has been changed (Stuss, Levine, & Alexander, 2000).

A meta-analysis by Romine and Reynolds (2005) documented large reductions in perseverative errors on the WCST between 5 and 11 years, followed by smaller improvements up to the age of 14 years. Huizinga and van der Molen (2007) found that performance on the WCST is influenced by two processes: set switching and set maintenance. Whereas failure in set shifting is responsible for perseverative errors, failure in set maintenance results in distraction errors. Set shifting and set maintenance displayed different developmental trajectories and loaded on two factors in 7-year-olds, but on one factor in older children and adults (Huizinga & van der Molen, 2007). Performance on working memory and shifting tasks has been found to predict performance on the WCST, but results have not been entirely consistent and have varied by age (Huizinga et al., 2006; Huizinga & van der Molen, 2007).

The ToH and the ToL are the most widely used tests of planning (McCormack & Atance, 2011). Both tasks involve the transfer of objects (discs of gradated size, balls) on pegs from a starting configuration to a goal configuration in a minimum number of moves while observing a number of rules (see Bull, Espy, & Senn, 2004, on similarities and differences between the ToH and ToL). Problems differ in difficulty, which varies with the number of moves required for solution and the type of problem (e.g., tower-ending or flat-ending). The age at which children master ToH and ToL problems depends on problem difficulty, with performance on complex problems improving throughout adolescence (Romine & Reynolds, 2005).

Improvements on the Tower tasks have been linked to strategy use and inhibition. M. C. Welsh (1991) found that children's most common strategy in the TOH was to move a disc directly to the goal state even when this move was not optimal because the disc should have been moved into a temporary position that was not its final goal position. Based on the finding that 4-year-olds could solve three-move problems as long as these problems did not involve intermediate steps, Kaller, Rahm, Spreer, Mader and Unterrainer (2008) proposed that three-move problems without intermediate steps can be solved relying on a perceptual strategy. By contrast, three-move problems involving intermediate steps require that children plan ahead, and children may invest more time in planning as they grow older (Asato, Sweeney, & Luna, 2006).

The ability to inhibit the tendency to move the disc directly to the goal position when it needs to be moved to a temporary position might also affect performance. The finding that Tower performance is related to performance on measures of inhibition provides indirect support for this idea (Albert & Steinberg, 2011; Asato et al., 2006; Kaller et al., 2008; but see Huizinga et al., 2006). Interestingly, the importance of working memory and inhibition in children's performance on the ToH appears to change with age, suggesting that children approach the ToH in qualitative different ways at different ages (Senn, Espy, & Kaufmann, 2004).

To summarize, both the WSCT and Tower tasks show protracted development extending into adolescence. Performance on these tasks is due to the coordination of several processes. Further experimental studies are necessary to clarify the processes and strategies children employ in approaching these tasks at different ages.

The Development of Hot EF

A major criticism of traditional EF research has been that it neglects to incorporate affective and motivational processes, and, as a result, is not useful when the goal is to explain everyday functioning, which is saturated with emotional and motivational significance (e.g., Barkley, 2012). However, inspired by Damasio's (1994) seminal research emphasizing the role of affect in decision-making, there has been an increasing interest in "hot" emotional aspects of EF. Zelazo and colleagues (Zelazo & Carlson, 2012; Zelazo & Müller, 2002) introduced the distinction between relatively "hot" emotional aspects of EF typically associated with the OFC, and more cognitive, "cool" aspects typically associated with DLPFC. Cool EF is engaged in more emotionally neutral, decontextualized situations, and it is measured by typical working memory (span tasks) and flexibility tasks (e.g., DCCS). By contrast, hot EF exerts top-down control in emotionally significant situations, as when, for example, high gains or losses are at stake.

Delay tasks are classic examples of hot EF tasks (see Carlson, 2005). In the delay-of-gratification task, children must resist the temptation to take a smaller, immediate reward and wait to receive a larger reward later (Mischel, Shoda, & Rodriguez, 1989). Systematic research by Mischel and colleagues (1989) uncovered a variety of factors that influence the amount of time children can wait. For example, waiting was more difficult when the rewards (e.g., pretzels) were exposed and there were no distractions, or when attention was focused on the arousing qualities of the reward (e.g., taste). By contrast, waiting was made easier when children were asked to think about and focus attention on abstract qualities of the reward (e.g., imagining that pretzels are long brown logs), essentially turning the hot EF task into a cool EF task. Symbols may also serve such a cooling function. For example, Carlson, Davis, and Leach (2005) presented 3- and 4-year-olds with two piles of candy, one large and one small, and the children had to point to the small pile in order to obtain the large pile. Whereas 3-year-olds performed poorly when they had to point to the smaller reward, their performance improved significantly when the real rewards were replaced by abstract representations of the rewards.

The prototypical hot EF task is the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994). In the adult version of this task, participants are presented with four decks of cards that, when turned over, reveal a combination of gains and losses. Participants are instructed to gain as much money as possible by selecting one card per trial from whichever deck they choose. Unbeknownst to the participants, two of the decks are, in the long run, advantageous (small gains but also small losses) and two decks are disadvantageous (high gains but also very high losses). Whereas healthy adults learn over the course of trials to select cards from the advantageous decks, patients with lesions to the OFC continue to select cards from the disadvantageous deck. Research with child-friendly versions of the IGT has shown that advantageous choices increase significantly in the preschool years (Garon & Moore, 2004; Kerr & Zelazo, 2004), and continue to improve throughout adolescence (e.g., Crone & van der Molen, 2004).

Even though the exploration of emotional and motivational aspects of EF provides an exciting new avenue, the construct of hot EF needs further conceptual and empirical clarification. First, the necessary and sufficient conditions of what qualifies a task as hot versus cool are unclear. Even if hot and cool EF were only poles of a continuum, with every EF task being a mixture of hot and cool processes (e.g., Hongwanishkul, Happaney, Lee, & Zelazo, 2005), it would be helpful to have criteria that made it possible to order EF tasks along the hot-cool continuum in a nonarbitrary way. Second, as reviewed by M. C. Welsh and Peterson (2014), there is no compelling empirical evidence that demonstrates that hot and cool EF are separable. Correlational patterns are inconsistent with the prediction that hot EF tasks are more closely related to each other than cool EF tasks, factor-analytic studies do not always identify separate factors (Prencipe et al., 2011; but see Willoughby, Kupersmidt, Voegler-Lee, & Bryant, 2011), and it is unclear whether the development of hot and cool EF follows different trajectories. Third, hot EF tasks are often complex and involve numerous processes; as a result, it is unclear what processes underlie performance. For example, a variety of different explanations have been provided to account for the improvements on child versions of the IGT (e.g., Cassotti, Houdé, & Moutier, 2011; Crone & van der Molen, 2004; Huizenga, Crone, & Jansen, 2007; see Dunn, Dalgleish, & Lawrence, 2006, for a discussion of the adult version of the IGT). Fourth, if better performance on hot EF tasks depends on the cooling down of hot EF, then it is not clear what the role of hot EF would be, and how the developmental trajectory of hot EF could be separate from that of cool EF. Finally, depending on the context, hot processes may enhance or impair performance on EF tasks (e.g., Pessoa, 2009; Sinopoli et al., 2011). The effect of affective and motivational significance on EF needs to be further investigated, using systematic task manipulations that independently vary EF demands and affective-motivational significance.

Summary

A large amount of research provides detailed information about the development of different aspects of EF and their associated neural basis. The specific processes that EF tasks measure, however, often remain unclear. Experimental manipulations and decomposition of measures into lower-order processes are necessary to determine the cognitive basis of EF tasks. Longitudinal studies that examine the relations among EF components or lower-order processes would be helpful to ascertain whether different processes influence each other over time. Finally, the developmental origin of EF remains largely unclear. A number of processes have been proposed as developmental basis of EF, including attentional processes (Garon et al., 2008), self-control (Friedman, et al., 2011) and processing speed (Rose et al., 2012). The clarification of the developmental foundation of EF and its relation to attentional processes, self-control, and speed of processing is an important task for future research.

PROBLEMS IN THE ASSESSMENT OF EF

The assessment of EF in children raises some of the same problems as the assessment of EF in adults. Some problems, however, are unique to children. In this section we discuss the task impurity problem, fractionation, test-retest reliability and validity (with particular focus on ecological validity).

General Methodological Problems in the Assessment of EF

A number of methodological problems concerning the assessment of EF have been identified (Rabbitt, 1997). Chief among these is the task impurity problem (i.e., the difficulty to separate executive from nonexecutive demands). We already mentioned that CFA is increasingly used as a statistical method to address this problem. Another way of addressing the task impurity problem consists in the use of carefully designed control tasks such that the performance on a control task is compared to the performance on an executive task, which only differs from the control task by making demands on executive processes. For example, for the Stroop test, the control condition may consist in the letter *X* printed in a given color with the participant having to name the ink color. Subsequent analyses create difference scores by subtracting performance on the control task from the EF task, or focus on the variance in the EF task that cannot be explained by the control task (i.e., regression residuals).

Another problem in the assessment of EF is that each task may tap into multiple components of EF. For example, tower tasks may measure inhibition, flexibility, and working memory; even "simple" tasks like the backward span task may engage not only working memory but also inhibition because it requires the inhibition of the prepotent tendency to repeat items in the same order in which they were heard. The *via regia* to address this issue is the experimental method, which, in the case of EF, has both advantages and disadvantages as pointed out by Rabbitt (1997, p. 14):

> Explorations of executive function have used the classical methodology of human experimental psychology: to try to develop tasks in which we can control as many demand variables as possible in the hope of isolating, quantifying, and measuring the effects of some single critical variable that, speculatively, taxes one single hypothetical functional process and not others. It may be that this venerable strategy is entirely inappropriate for analysing executive function because an essential property of all "executive" behaviour is that, by its nature, it involves the simultaneous management of a variety of different functional processes.

Adoption of the experimental method thus may lead to the isolation of EF components (i.e., fractionation of EF) necessary for task success at the cost of losing the very essence of EF. The fractionation of EF may thus adversely affect the ecological validity of EF.

A methodological issue that is specific to the assessment of EF in young children arises from the limited language abilities of young children (Anderson & Reidy, 2012; Hughes & Graham, 2002). To some extent, this problem can be avoided by designing EF tasks with no or only minimal verbal requirements (e.g., Garon, Smith & Bryson, 2014; Müller et al., 2012). At a deeper level, the development of EF may depend on improvements in language abilities, and, consequently, it may, from a theoretical perspective, be misguided to separate language and EF (Hughes & Graham, 2002). Finally, in developmental studies the question arises whether the same task measures the same EF processes at different ages (i.e., measurement invariance). A number of cross-sectional and longitudinal studies have used CFA to examine measurement invariance (e.g., Shing et al., 2010; Wiebe et al., 2008; Willoughby, Wirth, & Blair, 2012). Overall, these studies provide evidence for strong measurement invariance of aggregate scores across different age groups and across time, but they also indicate that the relations between individual variables and latent factors change over time, suggesting that individual tasks engage different skills at different ages (e.g., Shing et al., 2010; Usai et al., 2014).

Test–Retest Reliability of Measures of EF

Compared to the research on developmental changes in EF and the factor structure of EF, surprisingly little information is available concerning the test–retest reliability of measures of EF in children. Retest reliability provides information about whether a measure consistently measures the same construct (i.e., its temporal stability), and, thus, about the amount of variability that is due to day-to-day fluctuations such as mood, changes in weather, and so on (Anastasi & Urbina, 1997). Satisfactory retest reliability ensures that task performance is a reflection of true variance (and not random error variability) in the construct of interest, a prerequisite for the valid measurement of any ability (Anastasi & Urbina, 1997). Reliability of EF measures is essential when examining individual differences and group differences (Beck, Schaefer, Pang & Carlson, 2011).

The assessment of retest reliability of EF tasks has been considered problematic because a central feature of many EF tasks is that they present participants with novel situations that require the generation of nonroutine responses (Burgess, 1997). Accordingly, as EF tasks are repeatedly administered, performance may become automatized, and may no longer draw on executive control, though this problem might be not be as significant in children as it is in adults (Hughes & Graham, 2002). Task novelty may relate to performance more directly in some EF tasks than in others. For example, repeated administration of a response inhibition task such as the go/no-go task, which requires participants to execute a response to one type of stimulus but suppress a response to a different type of stimulus, may lead to response automatization requiring higher levels of inhibitory control.

Novelty does not appear to be an essential feature in performance on working memory tasks. Indeed, studies have shown that working memory tasks display adequate temporal stability in children (e.g., Alloway, Gathercole, & Pickering, 2006; Kuntsi, Stevenson, Osterlaan, & Sonuga-Barke, 2001; Müller et al., 2012; Schmid et al., 2008; Zelazo et al., 2013). By contrast, findings regarding the retest reliability of tasks that involve the inhibition of prepotent responses and shifting have been more variable, ranging from poor ($r_{tt} < .30$) retest reliabilities for some measures of inhibition (Knock Tap Game) and shifting (Wisconsin Card Sorting Test) to adequate retest reliability ($r_{tt} > .70$) for other measures of inhibition (e.g., Luria's tapping test; e.g., Archibald & Kerns, 1999; Kuntsi et al., 2001). Similarly, measures of planning such as the Tower of Hanoi, which may also be strongly affected by task novelty, have not consistently produced satisfactory temporal stability in school age children (e.g., Bishop, Aamodt-Leeper, Creswell, McGurk, & Skuse, 2001; Müller et al., 2012). Batteries of EF (National Institutes of Health [NIH] Toolbox Cognition Battery [Zelazo et al., 2013]; Willoughby & Blair, 2011) have shown excellent test-retest reliability. Willoughby and Blair (2011) calculated the test-retest-reliability for latent EF ability and found it to be significantly higher than that of individual measures of EF. However, they also noticed that individual tasks measured EF at different levels of ability with different precision (Willoughby, Wirth & Blair, 2012). To improve test-retest reliability, researchers should aggregate over conceptually similar measures. This follows from the principle of aggregation, which holds that multiple measures of the same construct provide a more stable and representative indicator than any single measure (Rushton, Brainerd, & Pressley, 1983).

Validity of Measures of EF

Whereas the validity of EF measures that are used for the purpose of neuropsychological assessment often is systematically determined (Lezak et al., 2004), this is frequently not the case for measures of EF used in developmental research. One exception is the NIH Toolbox Cognitive Battery (CB), which includes measures of working memory, shifting (DCCS), and inhibition (flanker task; Bauer & Zelazo, 2013). The developers of the NIH toolbox CB undertook systematic efforts to establish the convergent as well as the discriminant validity of measures included in the battery. For example, the Wechsler Preschool and Primary Scale of Intelligence, Third Edition (WPPSI-III) Block Design test (for 3- to 6-year-olds) and the inhibition scale from the Delis-Kaplan Executive Function System (D-KEFS) for 8- to 15-year-olds were used to establish convergent validity for the CB measures of inhibitory control and shifting, and the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-IV) was used to establish discriminant validity. Overall, tests used to establish convergent and discriminant validity showed moderate correlations with EF tasks, with younger children demonstrating poorer discriminant validity than older children, a finding consistent with the idea that cognitive functions specialize with development (Bauer & Zelazo, 2013).

In the past decade, the ecological validity of EF tasks has received considerable attention. This is partly due to the important role EF tasks play for clinical psychologists and neuropsychologists in predicting behavior in everyday settings. From this perspective, lab-based EF (or performance-based measures) have been criticized as being too narrow and often failing to accurately capture children's and adults' real-world functioning (Barkley, 2012; Bodnar, Prahme, Cutting, Denckla, & Mahone, 2007). Indeed, adult patients with lesions to the PFC can perform well on standard measures of EF (like the WCST), but nevertheless show marked impairments in everyday life (Shallice & Burgess, 1991). Barkley (2012) argues that performance-based measures of EF suffer from poor ecological validity, failing to incorporate important features of EF (e.g., volition, will, motivation), with short sampling windows of behavior (e.g., 10 minutes per test), and are thus unable to capture the protracted duration of goal-directed activities that are the essence of EF. In addition, many EF tasks demand relatively simple responses to simple events, whereas goal-directed actions in everyday contexts typically require a more complicated series of steps, including goal and subgoal setting, prioritization of subgoals, quick and flexible revision of subgoals depending on the evaluation of the context and feedback from the environment.

One direction that researchers have taken to provide more ecologically valid measures of EF has been the development of parent and teacher rating scales of EF (for an overview, see Toplak, West, & Stanovich, 2013). A widely used parent and teacher report measure of EF, the Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000) consists of eight individual scales and three composite scores: the Inhibition, Shift, and Emotional control scales make up the Behavioral Regulation composite, the Initiate, Working Memory, Plan/Organize, Organization of materials, and Monitor scales make up the Metacognitive composite, and the Behavioral Regulation and Metacognitive composites can be added to form a Global Executive composite score. The instrument consists of 86 items that describe behaviors in a variety of different everyday situations and parents and teachers must indicate how often the target child displays difficulties with that behavior (Never, Sometimes, Often). For example, the Inhibition scale measures the reporter's (e.g., teacher, parent) perception of the child's ability to resist responding or acting on an impulse and to stop his or her behavior at the appropriate time. Compared to performance-based measures, rating instruments have the advantage of allowing the researcher to gather information about a target child from a person who knows the child well and can base the rating on his or her experience with the child across a variety of different settings (Barkley, 2012). Rating instruments, however, have several problems, including the possibility that the rater is not in a position to provide an accurate evaluation of the child's behavior, or has inadequate experience with children and may be evaluating the child based on age-inappropriate behavioral expectations.

In a review of research that examined the association between performance-based and rating measures of EF, Toplak and colleagues (2013) found that the median correlation was quite low, at only $r = .19$. A study by Liebermann, Giesbrecht, and Müller (2007) examined the relations between different components of EF (inhibition, working memory, shifting) and emotion regulation to corresponding scales on the BRIEF in preschoolers; none of the EF components had significant zero-order correlations with the corresponding BRIEF scale. In an analysis of the differences between performance-based measures of EF and rating instruments Toplak and colleagues (2013) note the differences in the way these measures of EF are administered and scored. While performance-based measures are typically highly structured (e.g., rules are provided), include considerable direction from the experimenter (e.g., feedback), and require relatively simple behavioral responses, rating instruments are less restrictive and assess relatively complex behavior. Based on these differences, Toplak and colleagues (2013; see also Barkley, 2012) suggest that performance-based measures and rating instruments likely tap into different aspects of functioning. Performance-based measures assess the algorithmic level of functioning, a level that is concerned with the efficiency with which an individual can recruit EF processes in the context of a task. Rating instruments, on the other hand, assess EF at a reflective level of functioning, a level that is concerned with the person's goals, with beliefs relevant to those goals, and the choice of the optimal action given these beliefs and goals. The issue of rational choice is entailed in the rating instruments of children's everyday behavior but it is bypassed in performance-based measures in which the goal is determined by the experimenter. Toplak and colleagues conclude that both measures provide useful information; performance-based measures inform us about how well an individual can perform under highly structured conditions, and rating instruments inform us about the individual's typical performance level.

Researchers have tried to address the ecological validity of performance-based EF tasks by developing EF tasks that simulate the complexity and open-ended nature of problem solving in everyday settings. Examples are multitasking tests such as the Multiple Errands Test (Shallice & Burgess, 1991), the Six Elements subtest of the Behavioural Assessment of the Dysexecutive Syndrome (BADS; B. A. Wilson, Alderman, Burgess, Emslie, & Evans, 1996), and the planning of an unexpected party (Pentland, Todd, & Anderson, 1998). In these tests, participants are required to work on a series of tasks (e.g., completing arithmetic problems, writing down the names of pictures of objects printed on a series of cards) that they must attempt within a specified time frame. They are also given a number of rules that they must follow in order to complete the test correctly (e.g., they must try each of the tasks). Adult patients with frontal lesions showed impairments on these objective performance-based multitasking tests but not on typical EF performance-based measures, and performance on the former tests was highly correlated with difficulties in daily life (Shallice & Burgess, 1991). Similarly, using a modified, child-oriented multitasking test, Siklos and Kerns (2004) found that children with attention-deficit/hyperactivity disorder performed significantly worse on the multitasking test than a control group of typically developing children, and performance on the multitasking task correlated with their parent-reported behavioral and attentional problems at home.

Summary

A challenge in the assessment of EF consists in designing reliable measures that retain their ecological validity. Usually, high test–retest reliability is a prerequisite of validity, but in the assessment of EF, emphasis on test-retest reliability may, paradoxically, sometimes occur at the expense of construct validity. Future research should invest more effort in assessing EF in everyday-like contexts and in examining the relations between objective performance-based measures in the lab or clinic, less structured objective measures, and behavior rating scales of EF, and ascertain how each of these measures relates to different aspects of functioning.

INFLUENCES ON THE DEVELOPMENT OF EF

Given the importance of EF for psychological functioning, there has been a growing interest in factors that influence intraindividual change and interindividual differences in EF. In this section, we summarize studies that investigated the contributions of genetics, social context, and language on EF, and also discuss training and intervention studies conducted with the goal of ameliorating EF deficits.

Genetic Influences on EF

Two techniques that have been applied to assess the role of genes in the development of EF are molecular genetics and quantitative genetics (for reviews, see Barnes, Dean, Nandam, O'Connell, & Bellgrove, 2011; Morton, 2010). Molecular genetics are used to investigate how allelic association in a polymorphism is associated with performance on EF tasks. For example, using a candidate gene approach, Diamond, Briand, Fossella, and Gehlbach (2004) found that polymorphic variation on a gene (COMT) that codes for an enzyme involved in the breakdown of the neurotransmitter dopamine in the PFC was associated specifically with performance on a switching task that made working memory and inhibition demands; this type of task previously had been shown to be sensitive to dopamine levels in PFC in adult Parkinson's patients.

Quantitative genetics studies frequently employ the twin-study design to assess the proportion of variance in a trait that is attributable to genetic influences. Twin studies that examined the heritability of EF using individual tasks have found moderate heritability estimates (e.g., Godinez, Friedman, Rhee, Miyake, & Hewitt, 2012). Because of the task impurity problem, however, findings based on individual EF tasks are difficult to interpret. Combining the twin-study design with a latent-variable approach, Friedman and colleagues (2008) found that variance in the common EF factor was almost entirely (98% or 99%, depending on the model) explained by genetic influences. In addition to the extremely strong genetic influences on common EF, there were also very strong genetic influences on updating (100%) and shifting (76%), suggesting that the set of genes contributing to the variance in common EF are different from those contributing to variance in specific EF abilities. Secondary analyses showed that the genetic influences on EF did not simply reflect perceptual processing speed or IQ. The shared environment had no influence on either common EF or specific EF factors (0% variance explained), and the influence of the nonshared environment on EF was significant (13%) only for the shifting factor. Based on these findings, Friedman et al. (2008, p. 216) conclude that "individual differences in EFs are almost entirely genetic . . . , placing them among the most heritable psychological traits, possibly even more heritable than IQ."

Taken together, molecular and quantitative genetics studies suggest that EF is under strong genetic control, and that social context has very little impact on interindividual differences in EF. Next, we review studies that have assessed the impact of distal and proximal social factors on individual differences in EF; we return to the interpretation of the molecular and quantitative genetics studies at the end of this section.

Influences of the Social Context and EF

Studies of animals and humans have provided considerable evidence that the development of PFC and EF is experience dependent (Müller, Baker, & Yeung, 2013). We know from animal work that there are significant prenatal effects on PFC as a function of environment. Kolb and colleagues (2012) have documented the timeline of the development of the PFC in a rat model with overproduction of synapses occurring from birth through Day 40 (human equivalent of prenatal through Age 12) and prefrontal pruning from Day 35 through into adulthood, with myelination occurring throughout that time period. Evidence from this experimental animal work suggests that when the PFC is exposed to different environmental events during development, it develops in different ways, with relative changes in over- or underproduction of dendritic spines in the orbital frontal cortices, or medial PFC varying as a function of the event. Interestingly, events that affected development of these cortical regions varied widely and included prenatal (maternal) stress (even bystander stress), early experiences with both the mother and the father, peer relationships, and many aspects of environmental stimulation/enrichment or lack thereof (Kolb et al., 2012).

Socioeconomic Status

Consistent with the animal work, studies involving children also demonstrate experience-dependent development of the PFC (see Mackey et al., 2013, for a review). For example, socioeconomic status (SES) has been linked to electrical activity and cortical thickness of the PFC (Kishiyama, Boyce, Jimenz, Perry, & Knight, 2008; Lawson, Duda, Avants, Wu, & Farah, 2013). The effects of SES are discernible already early in development. Tomalski and colleagues (2013) obtained high-frequency (gamma) resting state EEG oscillations while 6- to 9-month-old infants were watching videos, and found significantly reduced resting state frontal gamma power in infants from low-SES homes (income, maternal occupation) compared to infants from high-SES homes. The effects of SES were specific as there were no differences for occipital and temporal scalp areas, and could not be attributed to infants' sleep pattern. Tomalski and colleagues speculate that reduced frontal gamma power may be linked to greater risk of subsequent poor language skills and deficits in selective attention.

Consistent with the evidence on the association between SES and PFC, numerous studies have shown SES-related differences in EF performance (see Müller et al., 2013, for a review). For example, one study showed that 4-year-old children from homes with unsatisfied basic needs (e.g., overcrowding, inadequate housing conditions) performed significantly more poorly on measures of interference control, inhibitory control, planning, and working memory than children from homes with satisfied basic needs, even after controlling for IQ (Lipina et al., 2013). However, findings on whether SES selectively affects EF or performance on other non-EF tasks as well are inconsistent (Noble, McCandliss, & Farah, 2007).

The association between SES and PFC/EF by itself is open to different interpretations. Innate differences in PFC/EF could lead to different degrees of social success (social selection) or differences in SES could lead to differences in PFC/EF (social causation). It is also possible that innate differences in PFC/EF interact with social conditions to influence neurodevelopmental outcomes (Hackman, Farah, & Meaney, 2010). Evidence from mental health and IQ research supports the social causation theory (see discussion by Hackman et al., 2010). Furthermore, the finding by Raver and colleagues (as cited in Blair & Raver, 2012) that EF is affected by the chronicity of adversity and fluctuates with socioeconomic changes (Blair & Raver, 2012) is also difficult to explain via social selection theory.

Parenting

SES is a distal factor that can exert its effect on brain development and EF indirectly, through mediating factors such as "cognitive stimulation in the home, toxins, nutrition, prenatal drug exposure and stress—including parental stress and its associated effects on parenting practices and parent-child interactions" (Hackman et al., 2010, p. 653). Several of the factors listed by Hackman and colleagues (2010) have been shown to influence PFC and EF. Postnatal stressors, such as traumatic events and institutionalization negatively affect PFC volume, are linked to poorer performance on EF tasks and perturbations in associated neural correlates (e.g., Carrion, Weems, Richert, Hoffman, & Reiss, 2010; Lewis-Morrarty, Dozier, Bernard, Terracciano, & Moore, 2012; McDermott, Westerlund, Zeanah, Nelson, & Fox, 2012). Cognitive stimulation in the form of literacy activities (e.g., picture book reading) and access to computers mediates the effects of low SES on EF as well (Lipina et al., 2013). Finally, there is evidence that parenting partially mediates the relation between SES and EF (Blair et al., 2011; Dilworth-Bart, Poehlmann, Hilgendorf, Miller, & Lambert, 2010). For example, Blair and colleagues (2011) found that positive parenting (e.g., positive regard, sensitivity) and negative parenting (intrusiveness, negative regard) in the context of free play (as assessed when children were 7 and 15 months old) mediated between exposure to poverty and EF at age 3 years. Furthermore, positive parenting was inversely related to children's resting cortisol levels at ages 7, 15, and 24 months, suggesting that supportive parents helped regulate children's stress reactivity "to facilitate reflective and flexible forms of behavior and cognition, such as executive functions" (Blair et al., 2011, p. 1980).

Several longitudinal studies have examined in more detail the role of various aspects of the parent–child relationship in promoting EF. This research has shown that parental scaffolding (i.e., the provision of developmentally sensitive support offered by parents to their child in a problem solving situation) predicted better performance on EF in preschool children (Bernier, Carlson, & Whipple, 2010; Conway & Stifter, 2012; Dilworth-Bart et al., 2010; Hughes & Ensor, 2009; Matte-Gagné & Bernier, 2011). For example, in a longitudinal study by Hammond, Müller, Carpendale, Bibock, and Liebermann-Finestone (2012), the amount of scaffolding a parent provided in a joint problem solving task presented in the lab at 2 and 3 years of age predicted 9% of variance in EF performance when children were tested at 4 years of age, even after controlling for prior EF, verbal ability, and gender. Further longitudinal studies have identified other aspects of parenting including mother-infant attachment, parenting practices and global family variables such as family chaos as being predictive of EF, even after controlling for prior EF (e.g., Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Blair & Raver, 2012; Hughes & Ensor, 2009). Positive parenting also seems to be a protective factor, as it was found that positive parenting buffered the impact of neurological risk (i.e., corpus callosum length as measured in infancy) on parent-rated inhibition problems in preschoolers (Kok et al., 2013).

Even longitudinal studies that control for prior EF cannot rule out the possibility that a third variable (and not parenting) is responsible for individual differences in EF. One candidate for such a third variable is child temperament, which has been shown to moderate the effects of parenting (e.g., Kim & Kochanska, 2012). Conway and Stifter (2012) conducted the only study thus far that examined the effects of scaffolding on EF in the context of children's temperament. They found that maternal attention-maintaining at the age of 2 years predicted better performance on conflict inhibition tasks 2½ years later for temperamentally inhibited and exuberant children, but not for low-reactive children. Maternal attention-redirecting predicted poorer delay inhibition and conflict inhibition for inhibited children.

There is little research on the influence of siblings and peers on the development EF (McAlister & Peterson, 2013). Unless scaffolded, younger preschoolers may encounter difficulties in establishing well-coordinated action sequences with a partner (e.g., Meyer, Bekkering, Paulus, & Hunnius, 2010), but it has been suggested that older preschoolers benefit from sociodramatic play (Vygotsky, 1978; see Lillard, Chapter 11, this *Handbook*, this volume) and sociocognitive conflict that arises in communication and cooperation (Duveen & Psaltis, 2008) might spur the development of EF.

Even though the empirical evidence supports the idea that parenting affects individual differences in EF, this line of research leaves a number of questions unanswered that should be addressed by future research.

1. It is unclear how the different aspects of parenting are related and whether they are equally important at different points in development. Even studies that focused on scaffolding need to clarify what aspects of scaffolding (e.g., verbal support or nonverbal support; see Hammond et al., 2012) are most effective.
2. The studies have been limited to preschool children; the contribution of parent–child interactions to individual differences in EF in older children has not been investigated.
3. Different aspects of caregiving should be examined in different contexts to gauge their relative impact on individual differences in EF.
4. Almost all extant parent-child interaction studies included only the mother. As a consequence, the contribution of the quality of father–child interaction to interindividual differences in EF is unclear. Notably, evidence from attachment research suggests that fathers' sensitive and challenging interactions in the context of playful interactions affect subsequent development (Grossmann et al., 2002).
5. Future studies should use more sophisticated designs and statistical methods to address the possibility that a third variable drives the relation between parenting and EF (see Willoughby, Kupersmidt, & Voegler-Lee, 2012), and to examine more closely reciprocal effects between scaffolding and EF.

The Influence of Language on EF

Research on the influence of language on EF was stimulated by Vygotsky's and Luria's theories. We review these theories first, before we turn to a summary of current research studies that have examined the relation between language and EF.

Vygotsky and Luria's Theories

Vygotsky's sociocultural theory provides the foundation for attempts to explain the development of EF in terms of social interaction (see Gauvain & Perez, Chapter 20, this *Handbook*, this volume). Central for Vygotsky was the idea that development proceeds from the social to the individual. This is stated in his *genetic law of cultural development*, according to which any function in the child's cultural development appears twice, or on two planes. First, it appears on the social plane, and then on the psychological plane:

> The most important and basic genetic laws . . . reads that every symbolic activity of the child was once a social form of co-operation and preserves throughout its development, to its highest point, the social method of functioning. The history of higher psychological functions is disclosed here *as the history of the transformation of means of social behaviour into means of individual psychological organization*. (Vygotsky & Luria, 1929/1994, p. 138; emphasis in original)

The development of speech is a prime example for the genetic law of cultural development. Children use speech initially in an interpersonal, communicative context, to steer the consciousness of an interlocutor, and they are, in turn, the recipients of speech acts of others. Speech is then gradually internalized, and children use it to steer their own behavior. At a transitional stage of this internalization process, this self-directed or private speech is still audible, but with development it will turn into silent, inaudible speech (Vygotsky, 1934/1986).

Self-directed speech is the prerequisite for and involved in all higher cognitive functions. It frees the child from the immediate perceptual field, allowing the child to plan solutions in advance:

> The child is much more easily able to ignore the vector that focuses attention on the goal itself, and to execute a number of complex preliminary acts, using for this purpose a comparatively long chain of auxiliary instruments. The child proves able to include independently, in the process of solution of the task, objects which lie neither within the near nor the peripheral visual field. By creating through words a certain intention, the child achieves a much broader range of activity, applying tools not only to those objects which lie near at hand, but searching for and preparing such articles as can be useful in the solution of its task and planning its future operation. (Vygotsky & Luria, 1929/1994, p. 110)

Speech thus transforms the child's relation to the world; with the help of speech she transcends the here and now, and the use of speech makes her behavior in problem-solving situations more planful and deliberate. At the same time, speech transforms the child's relation to him- or herself and his or her own behavior, with the same consequence: "With the aid of speech the child for the first time proves able to the mastering of its own behaviour, relating to itself as to another being, regarding itself as an object. Speech helps the child to master this object through the preliminary organization and planning of its own acts of behaviour" (Vygotsky & Luria, 1929/1994, p. 111).

The use of speech for planning and self-objectification is rooted in and develops out of the social function of speech. For Vygotsky, then, all higher forms of consciousness can ultimately be traced back to social interactions.

Vygotsky's colleague Luria (1959, 1961) further elaborated on the regulatory function of speech. A key finding from his research is that with age, children are able to use increasingly complex verbal commands to guide their behavior. For example, Luria assessed the effects of labeling on a go/no-go task. In this task, children were asked to press a bulb when a red light came on (go trials), and they were asked to refrain from pressing when a blue light came on (no-go trials). Luria found that 3-year-olds had difficulty on the basic version of the task, whereas older preschoolers tended to do well. Moreover, when 3-year-olds were asked to accompany their manual responses (i.e., pressing on go trials) with self-directed commands such as "Press," they were better at regulating their responses. By contrast, when 3-year-olds were asked to accompany their non-responses (i.e., withholding responding on no-go trials) with self-directed commands such as "Don't press," their performance on no-go trials worsened. This was not true for older children, however, as their performance improved when they labeled both on go and no-go trials. Luria argued that at the age of 3 years, children can regulate their behavior using the expressive and physically impulsive aspect of labels, but are still unable to govern their behavior using semantic aspects of labels; older preschoolers begin to use the meaning of labels to govern their behavior.

To summarize, according to Vygotsky and Luria, the speech that adults use in interpersonal exchanges with the child is gradually internalized by the child and then used by the child herself to regulate her behavior. The regulatory function allows children to organize and plan their behavior more efficiently. Initially, children rely on the physical aspects of speech but they become increasingly dependent on the semantic aspect of speech.

Empirical Studies on the Relation Between Language and EF

Following the ideas of Vygotsky and Luria, several studies have examined how the development of EF is related to language in general and private speech in particular. Several research studies have examined how vocabulary size (a semantic aspect of language) is related to individual differences in EF, and how private speech (or the suppression of private speech) and experimenter-induced labeling affect performance on EF tasks. Cross-sectional studies provide evidence that verbal ability, which in most studies is operationalized by measures of receptive vocabulary, in preschool children is significantly related to particular components of EF—particularly flexibility and working memory (see Müller, Jacques, Brocki, & Zelazo, 2009, for a review), and longitudinal data shows that receptive vocabulary at the ages of 2 and 3 years is significantly correlated with EF at subsequent ages (Hughes & Ensor, 2009). Furthermore, Fuhs and Day (2011) found that receptive and expressive verbal ability predicted fall to spring changes in EF in preschoolers (but see Hughes et al., 2010). Further evidence for the importance of verbal ability for EF comes from the findings that verbal ability mediates the relation between SES and EF (Catale, Willems, Lejeune, & Meulemans., 2012; Noble et al., 2007; Noble, Norman, & Farah, 2005; but see Sarsour et al., 2011) as well as the relation between scaffolding and EF (Landry, Miller-Loncar, Smith, & Swank, 2002; partial mediation: Hammond et al., 2012, Matte-Gagné & Bernier, 2011).

More direct tests of Vygotsky's idea that private speech supports planning have examined the role of private speech in planning tasks. Using the ToL as a measure of planning, Fernyhough and Fradley (2005) found that 4- to 5-year-olds' private speech peaked at intermediate levels of task difficulty (levels of task difficulty pitched within children's ability range or zone of proximal development). Furthermore, the frequency of task-relevant (overt or covert) private speech was related to concurrent, but not to future task performance (the same task was administered on multiple sessions, several days apart). However, contrary to predictions, it was not only task-relevant private speech that peaked with moderate task difficulty; all types of private speech, even irrelevant, peaked at this level, and relations between self-regulatory (i.e., relevant) private speech and task performance were not strongest for problems at the intermediate level. Item-by-item analysis provided some support for meaningful speech–outcome relations, with the simplest problems most frequently accompanied by silence and success, and the most complex problems tending to be associated with task-relevant private speech and failure.

The finding that private speech enhances performance on the ToL was partially replicated in a study with 4- to 8-year-old children (Al-Namlah, Fernyhough, & Meins, 2006). In a small-scale study using a microgenetic design, Benigno, Byrd, McNamara, Berg, and Farrar (2011) observed that abrupt increases in preschoolers' performance on the ToL were preceded by increases in on-task private speech relative to off-task private speech.

Even though an association between private speech and task performance is a necessary condition for inferring that private speech mediates planning, it is not a sufficient condition because private speech may simply accompany performance, without doing any work. An alternative approach to examining the role of private speech is articulatory suppression. This approach was pioneered by Sokolov (1972), who introduced different methods of suppressing inner speech during the execution of cognitive activities. For example, Sokolov had participants produce syllables ("lalala"), words, and verses from familiar poems while performing a cognitive task (he also impeded speech movements by fixating the lips and the tongue between the teeth, by, for example, keeping the mouth open with slightly protruded tongue). The logic underlying articulatory suppression is that if private speech has a causal role in performance on a primary task, then the articulatory suppression task should interfere with performance on the primary task. Lidstone, Meins, and Fernyhough (2010) employed articulatory suppression to assess the performance of 7- to 10-year-olds on the ToL. Children in the articulatory suppression condition had to repeat the word *Monday* at a constant rate, whereas children in the control condition had to tap their foot at a constant rate. Articulatory suppression impaired performance, but only when children were forced to plan ahead. Furthermore, participants who in the control condition produced more private speech on problems with intermediate difficulty, showed greater interference in the articulatory suppression condition (see also Kray, Eber, & Karbach, 2008). Fatzer and Roebers (2012) administered three EF tasks that differed in working memory demands: a complex span task, a flexibility task that required updating and inhibition, and a flanker task that demanded interference control. Fatzer and Roebers found that the effects of articulatory suppression were strongest for the complex span task, intermediate for the flexibility task, and absent for the flanker task. Furthermore, articulatory suppression impaired the performance of 9-year-olds to a larger extent than that of 6-year-olds, indicating that the performance of older children relied more heavily on private speech.

Lidstone and colleagues (2010) claim that their pattern of findings is consistent with the view that "cognition undergoes a domain-general shift toward mediation during early childhood" (p. 448). This claim receives further support from the research on the phonological recoding effect. This effect refers to the finding that drawings of items that are visually dissimilar but phonologically similar (e.g., bat, cat) are less accurately recalled than drawings of items that are phonologically dissimilar. It has been found that the phonological similarity for visually presented items is absent until the age of 6 to 7 years (e.g., Hitch, Halliday, Dodd, & Littler, 1989; Palmer, 2000). However, the findings by Fatzer and Roebers suggest that the mediational shift is not domain general but applies only to some EF tasks. Future research needs clarify more precisely which components of EF are impaired by articulatory suppression.

Following Luria's (1961) seminal work, several studies have examined the impact of experimenter-induced labeling on preschoolers' performance on EF tasks. Preschoolers are unlikely to label spontaneously in EF tasks, but their performance can be facilitated by inducing them to label (Müller, Zelazo, Hood, Leone, & Rohrer, 2004). For 3-year-olds, experimenter-induced labels appear to have a mostly attention directing function, not different from that of a pointing gesture (Jacques & Zelazo, 2005; Müller et al., 2004). Findings are inconsistent with respect to whether experimenter-induced labeling facilitates performance on the DCCS (Kirkham et al., 2003; Müller, Zelazo, Lurye, & Liebermann, 2008). At the age of 4 years, however, the effect of labeling appears to be no longer limited to attention-directing properties but stimulates a richer conceptualization of the task at hand. For example, presented with three cards and instructed to select two cards that were similar on one dimension (Selection 1) and then two cards that were similar on a different dimension (Selection 2), 4-year-olds performed significantly better on Selection 2 when they were asked to provide a label for Selection 1 (Jacques & Marcovitch, 2010). In addition to helping children to draw new inferences, task-relevant labels also facilitate the integration of event representations in 4-year-olds (Karbach, Kray, & Hommel, 2011; Kray, Eenshuistra, Kerstener, Weidema, & Hommel, 2006).

Kray, Kipp, and Karbach (2009) have shown that labeling the stimulus in a stop-signal task improved accuracy particularly for 7- to 9-year-olds, but that labeling the intended action ("stop," "go") or something irrelevant had no effect on task performance. The finding that labeling the intended action did not affect task performance suggests that labeling may not be effective for some types of inhibitory processes. Task-switching costs relative to performing a single task were also reduced in younger children (7- to 9-year-olds) and older adults when they were instructed to verbalize task-relevant words. By contrast, when they were instructed to verbalize irrelevant words, switch costs disproportionally increased for 7- to 9-year-old children and older adults compared to 11- to 13-year-old children and younger adults (Kray et al., 2008).

According to Kray and Ferdinand (2013), these findings suggests that in older children verbal labeling supports optimal task maintenance and preparation during task switching, particularly in situations where the environmental context provides no direct cue to task-appropriate behavior. Verbal labeling can thus be seen as a useful process for enhancing cognitive control.

Training Studies

The experience-dependent nature of EF is corroborated by mounting evidence suggesting that these abilities are sensitive to training (see Diamond & Lee, 2011, for a review). We distinguish between direct (targeted) and indirect approaches to training. Whereas direct training approaches target EF component processes, frequently through use of computerized programs that gradually increase the processing demands (mostly, working memory demands), indirect approaches target EF skills globally by integrating training into activities such as aerobic exercise and classroom curricula. Direct training approaches typically apply a massed practice approach to working memory (e.g., Thorell, Lindqvist, Bergman Nutley, Bohlin, & Klingberg, 2009), shifting (e.g., Kloo & Perner, 2003; Kray & Ferdinand, 2013), or response inhibition (Dowsett & Livesey, 2000). Findings from direct training studies vary widely, likely because training studies differ, among others, in terms of the amount of training, the variability of training, the type of sample, and the type of control group (e.g., passive waitlisted control group versus active control group that engaged in some sort of activity) (Kray & Ferdinand, 2013; Wass, Scerif & Johnson, 2012). Based on a meta-analysis of working memory training programs, Melby-Lervåg and Hulme (2012) stressed that the long-term effectiveness and transfer effects of working memory training need to be addressed more carefully. Wass and colleagues (2012) conducted a meta-analysis of the effectiveness of attentional control and working memory training and found evidence that training is more effective and more likely to transfer with younger participants. Children with poorer EF abilities may also benefit more from EF training than children with better EF abilities (Diamond & Lee, 2011; Kray & Ferdinand, 2013). Training effects may also manifest differently on neural and behavioral levels, necessitating the joint assessment of both levels of functioning (e.g., Rueda, Checa, & Cómbita, 2012). Furthermore, often unaddressed in training studies is the critical role of motivation, metacognition, and strategy training. Many advocates of direct training approaches have emphasized the importance of these components for the generalizability of trained skills to natural settings (Butler & Copeland, 2002; Kerns, MacSween, Vander Weeken, & Grupposo, 2010; Sohlberg & Mateer, 2001). Clearly, future research needs to address more systematically the factors that influence the effectiveness of direct training.

An alternative approach is to promote EF indirectly, by enrolling children in exercise programs (e.g., Best, 2012), musical training (Moreno et al., 2011), and activities that practice self-regulatory abilities such as mindfulness training (Zelazo & Lyons, 2012). In general, these holistic approaches have been shown to improve performance on EF tasks (see Diamond, 2012; Diamond & Lee, 2011, for reviews). Mindfulness-based interventions, for example, focus on training and monitoring one's attention and reflecting on the present moment in a nonjudgmental manner (e.g., Kabat-Zinn, 2003), and research on the benefits of mindfulness training in children has lately received considerable attention (Zelazo & Lyons, 2012). A study comparing a mindfulness-based program, integrative body–mind training (IBMT) to a general relaxation intervention found that preschoolers in the IBMT condition showed significantly changed amplitude of the event-related potential (ERP) related to ACC activity during a response inhibition task (Yang et al., 2010; as cited in Tang, Yang, Leve, & Harold, 2012). Zelazo and Lyons (2012) speculate that mindfulness-based interventions enhance EF by training sustained reprocessing and conscious reflection of information (top-down processes) and modulation of bottom-up influences that affect reactivity such as arousal, anxiety, and motivation.

Empirical evidence on positive effects of school-based interventions and school curricula on EF is mixed. Tools of the Mind is a curriculum inspired by Vygotskian ideas that promotes self-regulation and literacy skills in preschoolers and kindergarten children through encouraging sociodramatic play and self-regulatory speech (Bodrova & Leong, 2007). Although an initial evaluation study found that preschoolers who attended the Tools program outperformed controls (Diamond, Barnett, Thomas, & Munro, 2007), subsequent evaluation studies have failed to replicate this effect (see summary in Lillard et al., 2012). Evaluations of the effects of the Montessori curriculum on EF paint a more positive picture, with one study demonstrating that 5-year-olds attending Montessori schools performed significantly better than controls on measures of cognitive flexibility (Lillard & Else-Quest, 2006); a further study showed that preschoolers in classic Montessori programs (used only Montessori materials) showed significantly larger gains in EF from fall to spring than preschoolers in lower fidelity Montessori programs and conventional programs (Lillard, 2012).

Promoting Alternative Thinking Strategies (PATHS) is a school-based intervention program that emphasizes the integration of affect, behavior, and cognition (Greenberg, Kusche, Cook & Quamma, 1995). PATHS has been shown to promote EF among 7- to 9-year-olds. The improvement in EF in turn mediated PATHS intervention effects on problem behaviors (Riggs, Greenberg, Kusche, & Pentz, 2006). In a further study, 4-year-olds were randomly assigned to an enriched intervention Head Start REDI program that included the preschool PATHS curriculum or a control "usual practice" Head Start classroom (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008). Controlling for preintervention scores and a number of other variables, the results showed that children in the REDI program made significant gains on some measures of EF (i.e., shifting and task orientation). Furthermore, the combined intervention was particularly beneficial to the social competence and the control of aggressive behaviors of those children who had started the school year with lower levels of EF. Finally, improvements in EF skills, particularly task orientation, partially mediated intervention effects on emergent literacy and social-emotional competencies. Bierman and colleagues (2008) suggest that the creation of a supportive interpersonal environment in the REDI program (e.g., establishing rules and routines in classrooms, and promoting emotion regulation) positively affected EF.

EF can also be improved by training parents to interact with their children in ways that promote a secure attachment relationship. For example, the Attachment and Biobehavioral Catch-Up (ABC) intervention focuses on helping foster parents provide synchronous care and more nurturing responses to children's distress (Lewis-Morrarty et al., 2012). An evaluation study showed that preschool-age foster children who had received the ABC intervention performed significantly better on a measure of cognitive flexibility than foster children in an intervention control group. Furthermore, performance of foster children in the ABC intervention did not significantly differ from that of children who had never been in foster care (Lewis-Morrarty et al., 2012).

Summary

Drawing on research that examines the effects of social factors on individual differences in EF, we have provided concrete empirical examples that do not support the claim that EF is almost entirely heritable, and in fact provide evidence to the contrary. Further evidence for social influences on EF such as growing up bilingually (Bialystok, Craik, & Luk, 2012; but see Hilchey & Klein, 2011; Paap & Greenberg, 2013) or in a particular culture (Moriguchi, Evans, Hiraki, Itakura, & Lee, 2012; Sabbagh, Xu, Carlson, Moses, & Lee, 2006) were beyond the scope of this chapter but are important to note. We contrasted the quantitative genetics position with a sociocultural position and provided evidence for the importance of language and speech in the development of EF. Finally, we presented evidence from intervention research that demonstrates the plasticity and modifiability of PFC and EF.

Our review of the findings that social factors have a significant influence on EF does not appear to be compatible with the claim that EF is almost entirely heritable. However, as Miyake and Friedman (2012) are careful to point out, high heritability should not be equated with immutability: "*Heritability is the portion of variability* across individuals within a particular sample *attributable to genetic effects* at a particular point in time. *Thus, it says nothing about the source(s) of a particular individual's EF ability or the trainability of EFs within each individual or among a group of individuals*" (p. 11; emphases in original). Indeed, heritability only tells us something about the genetic influence on individual differences around a population mean, and it does not rule out the possibility that specific environmental influences such as targeted EF training may change the average EF (Friedman et al., 2008). However, if training can affect average EF, why did existing environmental variations in the study by Friedman and colleagues not account for more than 1% or 2% of variance in common EF and updating? After all, existing environmental variations can be considered as more or less effective forms of training (i.e., as more or less supportive of the development of EF).

The evidence discussed in this section is consistent with the developmental systems theory and a relational view of causality (Gottlieb, 2003, 2007; Lerner, 2011; Lerner & Overton, 2008; see Overton, Chapter 2, this *Handbook*, Volume 1). A developmental systems approach views genes as part of a developmental system that also encompasses the social and cultural contexts. Genetic activity does not determine developmental outcomes in a deterministic fashion; rather, developmental outcomes are characterized by a probabilistic epigenesis in the sense that there are bidirectional influences within and between different levels of analysis. We clearly need a better understanding of the different ways in which social-cultural context influences physiological and genetic activity. It is unclear to which extent different aspects of social life exert an independent influence on EF and its biological correlates. For example, a secure attachment relationship may influence the hypothalamic-pituitary-adrenal (HPA) axis and thus stress reactivity that in turn may facilitate the development of PFC (Bernier et al., 2012). Alternatively, a secure attachment relationship may facilitate more exploratory behavior that could stimulate the development of EF.

In the end, we agree with Meaney (2001; see also Mackey et al., 2013) that the very attempt to determine independent contributions of genes and environment is ill conceived:

> There are no genetic factors that can be studied independently of the environment, and there are no environmental factors that function independently of the genome. Phenotype emerges only from the interaction of gene and environment. The search for main effects is a fool's errand. In the context of modern molecular biology, it is a quest that is without credibility. Nature and nurture do not exist in a manner that can ever be considered independently quantifiable. There is, instead, simply a continuing process of development that emerges from the constant dialogue between gene and environment. (Meaney, 2001, p. 51)

IMPACT OF EF ON SOCIAL UNDERSTANDING AND ACADEMIC SKILLS

In this section we review research that has examined the influence of EF on other aspects of development. The research in this area is burgeoning, and we limit ourselves to two areas that have received considerable attention, namely, research on the relations between EF and social understanding, and research on the relation between EF and school readiness and achievement.

Executive Function and Theory of Mind

Concomitant to the dramatic changes we observe in EF, children between the ages of 3 and 5 years undergo important transitions in the understanding of their own and other people's mental life (theory of mind). In particular, around the age of 4 years children acquire an explicit (i.e., verbally articulated) understanding of false belief, which is often considered the hallmark in preschoolers' developing theory of mind as it reflects a differentiation between mind and world (i.e., children understand that someone can have a mental state that differs from reality; Perner, 1991; see Carpendale & Lewis, Chapter 10, this *Handbook*, this volume). An early meta-analysis conducted on the basis of 10 separate studies reported that the changes in false belief understanding and EF are not coincidental but are systematically correlated (Perner & Lang, 1999).

A variety of explanations have been offered to account for this empirical relation between false belief understanding and EF (Devine & Hughes, 2014; Moses, & Carlson, 2004; Moses & Tahiroglu, 2010). First, according to the expression account, the association between false belief understanding and EF is due to surface features of the tasks used to assess false belief understanding (i.e., false belief tasks make executive processing demands such as holding information in mind, suppressing a prepotent response; see Baillargeon, Scott, & He, 2010; Leslie & Polizzi, 1998). Second, according to the emergence account, EF is a prerequisite for the acquisition of false belief understanding (Moses & Carlson, 2004). Third, the metarepresentational account proposes that the development of the understanding of mental states is a prerequisite for EF because the ability to exert control over one's behavior requires the awareness (meta) of one's own mental representations (Perner & Lang, 2000). Fourth, according to the complexity account, performance on false belief and EF tasks is related because the tasks share a common level of perspectival or rule complexity (Frye et al., 1998; Kloo, Perner, & Giritzer, 2010; Zelazo & Frye, 1998).

Each of these proposals makes empirically testable predictions. The expression account predicts that removal of extraneous EF demands in false belief tasks should lead to success on false belief tasks. This prediction sets the expression account apart from the other accounts, which all stipulate a genuine developmental relation between EF and false belief understanding. The emergence account predicts that success in EF tasks should precede success in false belief understanding. Emergence accounts differ in terms of whether working memory (Gordon & Olson, 1998) or conflict inhibition (Moses & Carlson, 2004) serve as a prerequisite for false belief understanding. A problem for these versions of the emergence account is that they need to specify the particular level of EF development that children must have reached before they can succeed in false belief tasks.

The metarepresentational account predicts that success in false belief tasks should precede success in EF tasks. This account is confronted with the problem of having to clarify exactly which level of EF depends on false belief understanding, as already infants and toddlers succeed in some EF tasks. Complexity accounts predict that EF tasks and false belief tasks that share a similar level of complexity should be more closely related to each other than tasks that differ in terms of complexity. The challenge for complexity accounts consists in specifying, in a transparent and nonarbitrary manner, the complexity levels of EF and false belief tasks (and other measures of social understanding).

The controversy over the interpretation of the association between EF and false belief reasoning has created a flurry of research studies. Cross-sectional, longitudinal (e.g., Hughes & Ensor, 2007) and microgenetic (e.g., Flynn, 2007) designs, training studies (e.g., Kloo & Perner, 2003), and theoretically guided task manipulations (e.g., Hala, Hug, & Henderson, 2003) have been used to examine the relation between EF and false belief understanding. The relation between EF and false belief understanding has been studied in different countries (e.g., Sabbagh et al., 2006) and in different populations of atypically developing children (e.g., Dennis, Agostino, Roncadin, & Levin, 2009; Pellicano, 2007). More recently, this research enterprise has been expanded beyond the preschool age in both directions to include infants (Yott & Poulin-Dubois, 2012), toddlers (e.g., Hughes & Ensor, 2007), as well as adults and older adults (e.g., Philips et al., 2011), and it has broadened its focus to include other aspects of social understanding (e.g., understanding of desires, second-order false beliefs; see Carpendale & Lewis, Chapter 10, this *Handbook*, this volume).

A meta-analysis (Devine & Hughes, 2014) that included 102 studies (representing over 9,994 participants between the ages of 3 and 6 years from 15 countries) found a medium to large effect size ($r = .38$) for the relation between false belief understanding and EF; the effect size remained significant even after controlling for age and verbal ability ($r = .22$). This relation was similar for children with varying ages and from different cultures. The relation did not vary across different types of EF tasks (e.g., tasks that required delay inhibition or conflict inhibition), but it varied across different types of false belief tasks, with a stronger relation between EF and standard measures of false belief (e.g., change of location) than between EF and indirect (i.e., looking time) measures of false belief. Finally, analysis of 10 longitudinal studies supported an asymmetric relation between EF and false belief understanding such that EF precedes false belief understanding and not vice versa.

Overall, the findings of the meta-analysis clearly are incompatible with the prediction of the meta-representational account that false belief understanding precedes EF. Even though the developmental asymmetry between EF and theory of mind tasks is consistent with versions of the emergence account, failure to detect differential relations between EF tasks and false belief tasks does not fare well with either the working memory account or the conflict inhibition account. The failure to find differences in the strength with which less complex (e.g., delay tasks) and more complex measures of EF (DCCS) relate to false belief understanding is also not consistent with complexity theories. Indeed, the failure to find differences in the functional relations between different EF tasks and false belief understanding might reflect the relative undifferentiated structure of EF in preschoolers. Based on the interpretation of the shared variance of EF tasks, a new emergence account might need to explain the functional relation between EF and false belief understanding. However, as Devine and Hughes (2014) note, aggregation across studies might have resulted in effect sizes with larger standard error, making it difficult to detect moderator effects. Individual studies with systematically varied task demands have found that conflict inhibition tasks are more strongly related to false belief understanding than EF tasks that make either high inhibitory but low working memory demands (e.g., delay tasks) or low inhibitory and high working memory demands (e.g., backward span tasks; see Carlson, Claxton, Moses, 2014; Carlson, Moses, & Breton, 2002; Hala et al., 2003).

The finding that looking-time measures are less strongly related to EF than standard false belief tasks prima facie appears to support the expression account. However, findings from a number of studies conflict with the expression account. First, cross-cultural studies indicate that despite performing better on EF tasks than their age-matched peers in the United States and United Kingdom, Chinese and Korean preschoolers do not succeed earlier on false belief tasks (Sabbagh et al., 2006; Oh & Lewis, 2008). Second, a training study of false belief understanding showed that training success was predicted by inhibitory conflict ability at the outset of training but not by increases in EF ability in the course of training, as would be expected by the expression account (Benson, Sabbagh, Carlson, & Zelazo, 2013). Finally, one study demonstrated that false belief tasks that made low executive demands (e.g., distinguishing between *think* and *know*) were as strongly related to conflict inhibition as standard false belief tasks (Carlson et al., 2014).

Based on the findings of their meta-analysis, Devine and Hughes (2014) make a number of excellent suggestions for future research. The development of measures of different aspects of theory of mind for infants, toddlers, older children, and adults offers the opportunity to examine across the lifespan (a) whether the relation between EF and theory of mind remains stable or changes; (b) whether EF and theory of mind reciprocally influence each other; and (c) whether, as EF becomes more differentiated with age, there are changes in the functional relations between different components of EF and theory of mind. Finally, to understand the relation between EF and theory of mind it might be helpful to anchor firmly both in the context of social interaction because, as we reviewed earlier, parental scaffolding promotes—directly and indirectly via verbal ability—EF, and EF, in turn, may then promote the further development of theory of mind (see also Devine & Hughes, 2014).

EF, Emergent Academic Skills, and School Achievement

The contribution of EF to emergent academic skills (e.g., early counting, letter identification) as well as school achievement has received considerable attention in the last years (for a review, see Müller, Liebermann, Frye, & Zelazo, 2008). The possibility that EF predicts emergent academic skills is particularly important, as several studies have shown that preschoolers' emergent academic skills predict later school achievement (e.g., Duncan et al., 2007). Another important line of research with implications for intervention has investigated EF deficits in children with learning disabilities (e.g., Alloway & Gathercole, 2005; see Müller, Liebermann, et al., 2008).

There is clear evidence from cross-sectional and longitudinal studies that emerging academic skills and academic achievement are associated with composite measures and individual components of EF. For example, in a large-scale cross-sectional study, Willoughby, Blair, Wirth, and Greenberg (2012) established that a latent EF variable was significantly correlated with early literacy and math assessments in 5-year-olds. The correlations between the latent EF variable and academic achievement were stronger than correlations between individual EF tasks and academic achievement, demonstrating the value of CFA in controlling for measurement error and nonexecutive task demands (Willoughby, Blair et al., 2012). Evidence for a predictive relation between EF and academic skills and academic achievement has emerged from longitudinal studies. J. A. Welsh and colleagues (2010) found that growth in a composite measure of EF (i.e., working memory, inhibition, and attentional shifting) over the course of the prekindergarten year predicted (a) growth in literacy (i.e., identifying and saying letters and words) and math skills (i.e., numbers, quantities, counting, and simple arithmetic) between the beginning and end of the prekindergarten year, and (b) kindergarten reading and math achievement after controlling for growth in literacy skills, math skills, and verbal ability during the prekindergarten year. Similarly, C.A. Clark, Pritchard, and Woodward (2010) found that an EF composite at the age of 4 years explained about 30% of variance in mathematical achievement at the age of 6 years, and remained significant even after controlling for reading comprehension and IQ.

Findings from cross-sectional studies and longitudinal studies concerning the relative contribution of different components of EF to academic skills are somewhat inconsistent. For instance, there is evidence that individual differences in preschoolers' inhibition skills explain variance in later academic skills (Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007). Other studies, however, point to the importance of working memory for emergent academic skills and achievement. For example, Gathercole, Brown, and Pickering (2003) found that performance on working memory measures at school entry, when children were between 4 and 5 years old, predicted reading, writing, and spelling scores but not mathematics scores 2 years later, even after controlling for the baseline assessment of the academic skills when children were 4 years old. In contrast to Gathercole and colleagues, other studies have shown that working memory in preschoolers and primary school children makes a unique contribution also to later math achievement and number knowledge (e.g., Bull, Espy, & Wiebe, 2008; Lee et al., 2012; Monette, Bigras, & Guay, 2011; Van der Ven, Kroesbergen, Boom, & Leseman, 2012).

Few researchers have examined the relative contribution of shifting to preschoolers' school readiness, and most researchers that have included measures of shifting in their studies have not found significant relations between preschoolers' shifting and school readiness (Espy et al., 2004; Monette et al., 2011, but see Vitiello, Greenfield, Munis, &George, 2011). It may be the case that, during the preschool years, shifting is a relatively indistinct component of EF as suggested by latent variable studies of EF that do not support a unique shifting component in preschoolers (Miller et al., 2012; Willoughby, Blair, et al., 2010, 2012) or elementary school children (Lee et al., 2012; Van der Ven et al., 2012).

The finding that EF predicts future academic skills and achievement even after controlling for earlier academic skills cannot rule out the possibility that an unmeasured third variable drives the relation between EF and academic outcomes. To address this problem, Willoughby, Kupersmidt, and Voegler-Lee (2012) have suggested the use of fixed effects models to account statistically for time-invariant (stable) influences on academic outcomes that are not directly attributable to changes in EF. Fixed effects models are used on repeated measures data and are created by regressing differences in the outcome (e.g., change in academic achievement) on differences in the predictor (e.g., change in EF). This use of within-person comparisons provides a statistical basis for establishing causal associations that cannot be achieved with correlational or lagged analysis. In an example of the use of fixed effects models, Willoughby, Kupersmidt, and Voegeler-Lee (2012) administered measures of inhibitory control and measures of emergent academic skills to preschoolers at the beginning (fall) and end (spring) of the school year. Using the standard statistical approach to testing the relation between EF and emergent academic achievement, they found that inhibition predicted preschoolers' reading, writing, and math skills, thus replicating findings from previous longitudinal studies. However, when fixed effects models were used, these associations became nonsignificant, suggesting that the evidence for an association between EF and academic achievement is masked by other time-stable influences on academic achievement. Furthermore, the results using fixed effects analyses raise the question of whether the associations between EF and academic outcomes may be spurious, due to the presence of unmeasured third variables.

An alternative approach to ascertain corroborating evidence for a causal relation between EF and academic skills consists in the use of training studies. Two working memory training studies found that children who received working memory training showed improvements in their math skills (Holmes, Gathercole, & Dunning, 2009) and reading skills (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012). However, these studies failed to establish that the changes in working memory skills mediated changes in academic skills (i.e., no meditation analysis was conducted).

In this section, we reviewed evidence on the relation between EF and emergent academic skills and school achievement. Overall, research shows that EF is strongly associated with and predictive of academic outcomes, even though findings with respect to the relative contribution of different EF components to early literacy and math skills as well as to school achievement are inconsistent, probably due to differences in the measurement of EF and academic outcomes. Clearly, more studies are required that use longitudinal designs and latent variables to account for error variance. Further research on the relation between EF and emergent academic skills and academic achievement is also needed to determine whether a causal interpretation of this well-documented association is warranted. This research should more thoroughly assess whether training-based changes in EF components mediate changes in academic outcomes. Moreover, researchers in this field should employ more complex statistical models that control for potential confounds such as CFA, latent growth curve models, and fixed effects analyses. Finally, this research must ultimately clarify theoretically and empirically the exact process by which EF affects emergent academic skills and school achievement.

CONCLUSION

In this chapter, we reviewed influential theories of the development of EF and summarized empirical findings on the development of PFC and different components of EF. The methodological challenges research on EF has to face were the topic of the next section. The sources of EF development and interindividual differences in EF were examined in the next section, with particular emphasis on the ways in which social factors and language facilitate its development. Finally, we summarized research of the relations between EF and two other domains of functioning, namely, social understanding and academic skills. Throughout the chapter we evaluated the strengths and weaknesses of theories and approaches to particular problems, pointed out ambiguities and gaps in our knowledge, and made suggestions for future research.

In the concluding paragraphs, we reiterate the importance of giving more attention to theory building. It appears to us that the field is too task focused, at the expense of developing a comprehensive and integrative account of the development of EF. Theoretical efforts are particularly needed as the concept of EF has been charged with implying that there is a little man or homunculus inside the head who makes decisions and so on (Dick & Overton, 2010). One way of getting rid of the homunculus is to reduce psychological processes to neurological functioning. Martin and Failows (2010, p. 48) argue that

> such accounts strip component executive skills and abilities of the kinds of significance and meaning required for an adequate conceptualization and explanation of the kind of goal-directed activity that EF purports to be about. After all, relevant states and processes, including those in the PFC, although obviously necessary for the executive functioning of persons, do not by themselves envision, pursue, plan, and act in relation to tasks such as the *Tower of London* or the *Wisconsin Card Sorting Test*, let alone the multitude of tasks that confront us as we navigate our daily lives. . . . Consequently, any attempt to avoid the homunculus problem by neurophysiological reduction must be seen as inadequate in that we have no way of explaining how the neural patterns and properties invoked constitute or explain what needs to be explained.

A further, related problem is the *mereological fallacy* (Martin & Failows, 2010). Researchers commit this fallacy when they ascribe the psychological attributes to anything less than the person as a whole. For example, thinking or goal setting is not something that is done by a part of a person—be it the working memory system or an assembly of neurons in the PFC. Rather, goal setting and thinking are skills and capabilities that can be meaningfully applied only to the person as a whole.

We believe that in order to avoid these problems EF must be considered in the context of the person, and the development of EF must be explained as arising out of the activity of the embodied persons within a sociocultural context (Martin & Failows, 2010). Furthermore, we suggest that conceptualizing EF as a distributed, temporally extended functional process that with development gains in hierarchical complexity would provide a healthy foundation for any new comprehensive theory of EF and its development. Within such a framework, psychological and neurological processes can then be coordinated with and inform each other, rather than one being reduced to the other (see Overton, Chapter 2, this *Handbook*, Volume 1).

REFERENCES

Albert, D., & Steinberg, L. (2011). Age differences in strategic planning as indexed by the Tower of London. *Child Development*, *82*, 1501–1517.

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional Stroop phenomenon: A generic slowdown, not a Stroop effect. *Journal of Experimental Psychology: General*, *133*, 323–338.

Al-Namlah, A. S., Fernyhough, C., & Meins, E. (2006). Sociocultural influences on the development of verbal mediation: Private speech and phonological recoding in Saudi Arabian and British samples. *Developmental Psychology*, *42*, 117–131.

Alloway, T. P., & Alloway, R. G. (2013). Working memory across the lifespan: A cross-sectional approach. *Journal of Cognitive Psychology*, *25*, 84–93.

Alloway, T. P., & Gathercole, S. E. (2005). The role of sentence recall in reading and language skills of children with learning difficulties. *Learning and Individual Differences*, *15*, 271–282.

Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable? *Child Development*, *77*, 1698–1716.

Alloway, T. P., Pickering, S. J., & Gathercole, S. E. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable? *Child Development*, *77*, 1698–1716.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review*, *16*, 17–42.

Anastasi, A., & Urbina, S. (1997). *Psychological testing* (7th ed.). Upper Saddle River, NJ: Prentice Hall.

Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology*, *8*, 71–82.

Anderson, P. J., & Reidy, N. (2012). Assessing executive function in preschoolers. *Neuropsychological Review*, *22*, 345–360.

Archibald, S. J., & Kerns, K. A. (1999). Identification and description of new tests of executive functioning in children. *Child Neuropsychology*, *5*, 115–129.

Aron, A. R. (2007). The neural basis of inhibition in cognitive control. *Neuroscientist*, *13*, 214–228.

Asato, M. R., Sweeney, J. A., & Luna, B. (2006). Cognitive processes in the development of ToL performance. *Neuropsychologia*, *44*, 2259–2269.

Asato, M. R., Terwilliger, R., Woo, J., & Luna, B. (2010). White matter development in adolescence: A DTI study. *Cerebral Cortex*, *20*, 2122–2131.

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*, 1–29.

Baddeley, A., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Recent advances in learning and motivation* (Vol. 8, pp. 47–89). New York, NY: Academic Press.

Badre, D. (2008). Cognitive control, hierarchy, and the rostro-caudal organization of the frontal lobes. *Trends in Cognitive Sciences*, *12*, 193–200.

Baillargeon, R., Scott, R. M., & He, Z. (2010). False-belief understanding in infants. *Trends in Cognitive Sciences*, *14*, 110–118.

Band, G. P. H., van der Molen, M. W., Overtoom, C. C. E., & Verbaten, M. N. (2000). The ability to activate and inhibit speeded responses: Separate developmental trends. *Journal of Experimental Child Psychology*, *75*, 263–290.

Barbas, H. (1992). Connections underlying the synthesis of cognition, memory, and emotion in primate prefrontal cortices. *Brain Research Bulletin*, *52*, 319–330.

Barbey, A. K., Koenigs, M., & Grafman, J. (2013). Dorsolateral prefrontal contributions to human working memory. *Cortex*, *49*, 1195–1205.

Barkley, R. A. (2012). *Executive functions: What they are, how they work, and why they evolved*. New York, NY: Guilford Press.

Barnes, J. J. M., Dean, A. J., Nandam, S., O'Connell, R. G., & Bellgrove, M. A. (2011). The molecular genetics of executive function: Role of monoamine system genes. *Biological Psychiatry*, *69*, e127–e143.

Barrouillet, P., Bernardin, S., & Camos, V. (2004). Time constraints and resource sharing in adults' working memory spans. *Journal of Experimental Psychology, General*, *133*, 83–100.

Barrouillet, P., & Camos, V. (2011). Developmental change in working memory strategies: From passive maintenance to active refreshing. *Developmental Psychology*, *47*, 898–904.

Bauer, P. J., & Zelazo, P. D. (2013). NIH toolbox cognition battery (CB): Summary, conclusions, and implications for cognitive development. *Monographs of the Society for Research in Child Development*, *78*, 133–146.

Bechara, A., Damasio, A. R., Damasio, H., & Anderson S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*, *50*, 7–15.

Beck, D. M., Schaefer, C., Pang, K., & Carlson, S. M. (2011). Executive function in preschool children: Test-retest reliability. *Journal of Cognition and Development*, *12*, 169–193.

Becker, M. G., Isaac, W., & Hynd, G. W. (1987). Neuropsychological development of nonverbal behaviors attributed to frontal lobe functioning. *Developmental Neuropsychology*, *3*, 275–298.

Bell, M. A., & Fox, N. A. (1992). The relations between frontal brain electrical activity and cognitive development during infancy. *Child Development*, *63*, 1142–1163.

Benes, F. M., Turtle, M., Khan, Y., & Farol, P. (1994). Myelination of a key relay zone in the hippocampal formation occurs in the human brain during childhood, adolescence, and adulthood. *Archives of General Psychiatry*, *51*, 477–484.

Benigno, J. P., Byrd, D. L., McNamara, J. P. H., Berg, W. K., & Farrar, M. J. (2011). Talking through transition: Microgenetic changes in preschoolers' private speech and executive functioning. *Child Language Teaching and Therapy*, *27*, 269–285.

Benson, J. E., Sabbagh, M. A., Carlson, S. M., & Zelazo, P. D. (2013). Individual differences in executive functioning predict preschoolers' improvement from theory-of-mind training. *Developmental Psychology*, *49*, 1615–1627.

Benton, A. L. (1991). The prefrontal region: Its early history. In H. S. Levin, H. M. Eisenberg, & L. Benton (Eds.), *Frontal lobe function in dysfunction* (pp. 3–31). New York, NY: Oxford University Press.

Bernier, A., Carlson, S. M., Deschênes, M., & Matte-Gagné, C. (2012). Social factors in the development of early executive functioning: A closer look at the caregiving environment. *Developmental Science*, *15*, 12–24.

Bernier, A., Carlson, S. M., & Whipple, N. (2010). From external regulation to self-regulation: early parenting precursors of young children's executive functioning. *Child Development*, *81*, 326–339.

Bertolino, A., Saunders, R. C., Mattay, V. S., Bachevalier, J. Frank, J. A. & Weinberger, D. R. (1997). Altered development of prefrontal neurons in rhesus monkeys with neonatal mesial temporo-limbic lesions: A proton magnetic resonance spectroscopic imaging study. *Cerebral Cortex*, *7*, 740–748.

Berwid, O. G., Curko Kera, E. A., Marks, D. J., Santra, A., Bender, H. A., & Halperin, J. M. (2005). Sustained attention and response inhibition in young children at risk for Attention Deficit/Hyperactivity Disorder. *Journal of Child Psychology and Psychiatry*, *46*, 1219–1229.

Best, J. R. (2012). Exergaming immediately enhances children's executive function. *Developmental Psychology*, *48*, 1501–1510.

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*, 1641–1660.

Best, J. R., Miller, P. H., & Jones, L. L. (2009). Executive functions after age 5: Changes and correlates. *Developmental Review*, *29*, 180–200.

Beveridge, M., Jarrold, C., & Pettit, E. (2002). An experimental approach to executive fingerprinting in young children. *Infant and Child Development*, *11*, 107–123.

Bialystok, E., Craik, F., & Luk, G. (2012). Bilingualism: Consequences for mind and brain. *Trends in Cognitive Sciences*, *16*, 240–250.

Bianchi, L. (1922). *The mechanism of the brain*. Edinburgh, Scotland: E. & S. Livingstone.

Bierman, K. L., Nix, R. L., Greenberg, M. T., Blair, C., & Domitrovich, C. E. (2008). Executive functions and school readiness intervention: Impact, moderation, and mediation in the Head Start REDI program. *Development and Psychopathology*, *20*, 821–843.

Bishop, D., Aamodt-Leeper, G., Creswell, C., McGurk, R., & Skuse, D. (2001). Individual differences in cognitive planning on the Tower of Hanoi task: Neuropsychological maturity or measurement error? *Journal of Child Psychology and Psychiatry*, *42*, 551–556.

Blair, C., Granger, D., Willoughby, M., Mills-Koonce, R., Cox, M., Greenberg, M. T., . . . the FLP Investigators. (2011). Salivary cortisol mediates effects of poverty and parenting on executive functions in early childhood. *Child Development*, *82*, 1970–1984.

Blair, C., & Raver, C. C. (2012). Individual development and evolution: Experiential canalization of self-regulation. *Developmental Psychology*, *48*, 647–657.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647–663.

Blair, C., & Willoughby, M. (2013). Commentary. *Cognitive Development*, *28*, 350–353.

Blaye, A., Bernard-Peyron, V., Paour, J.-L., & Bonthoux, F. (2006). Categorical flexibility in children: Distinguishing response flexibility from conceptual flexibility; the protracted development of taxonomic representation. *European Journal of Developmental Psychology*, *3*, 163–188.

Bodnar, L. E., Prahme, M. C., Cutting, L. E., Denckla, M. B., & Mahone, E. M. (2007). Construct validity of parent ratings of inhibitory control. *Child Neuropsychology*, *13*, 345–362.

Bodrova, E., & Leong, D. J. (2007). *Tools of the mind: The Vygotskian approach to early childhood education* (2nd ed.). Columbus, OH: Merrill/Prentice Hall.

Botvinick, M. M., Niv, Y., & Barto, A. C. (2009). Hierarchically organized behavior and its neural foundation: A reinforcement learning perspective. *Cognition*, *113*, 262–280.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology*, *26*, 571–593.

Bryant, F. B., & Yarnold, P. R. (1994). Principle-components analysis and exploratory and confirmatory factor analysis. In L. G. Grimm & P. R. Yarnold (Eds.), *Reading and understanding multivariate statistics* (pp. 99–136). Washington, DC: American Psychological Association.

Bub, D. N., Masson, M. E. J., & Lalonde, C. E. (2006). Cognitive control in children: Stroop interference and suppression of word reading. *Psychological Science*, *17*, 351–357.

Bull, R., Espy, K. A., & Senn, T. E. (2004). A comparison of performance on the Towers of London and Hanoi in young children. *Journal of Child Psychology and Psychiatry*, *45*, 743–754.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205–228.

Burgess, P. W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 81–116). Hove, England: Psychology Press.

Butler, R. W., & Copeland, D. W. (2002). Attentional processes and their remediation in children treated for cancer: A literature review and the development of a therapeutic approach. *Journal of the International Neuropsychological Society*, *8*, 115–124.

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*, 595–216.

Carlson, S. M., Claxton, L. J., & Moses, L. J. (2014). The relation between executive function and theory of mind is more than skin deep. *Journal of Cognition and Development*. doi:10.1080/15248372.2013.824883

Carlson, S. M., Davis, A. C., & Leach, J. G. (2005). Less is more: Executive function and symbolic representation in preschool children. *Psychological Science*, *16*, 609–616.

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032–1053.

Carlson, S. M., Moses, L. J., & Breton, C. (2002). How specific is the relation between executive function and theory of mind? Contributions of inhibitory control and working memory. *Infant and Child Development*, *11*, 73–92.

Carrion, V. G., Weems, C. F., Richert, K., Hoffman, B. C., & Reiss, A. L. (2010). Decreased prefrontal cortical volume associated with increased bedtime cortisol in traumatized youth. *Biological Psychiatry*, *68*, 491–493.

Carver, A. C., Livesey, D. J., & Charles, M. (2001). Age related changes in inhibitory control as measured by stop-signal task performance. *International Journal of Neuroscience*, *107*, 43–61.

Case, R. M., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, *33*, 386–404.

Casey, B. J. (2001). Disruption of inhibitory control in developmental disorders: A mechanistic model of implicated frontostriatal circuitry. In J. L. McClelland & R. S. Siegler (Eds.), *Mechanisms of cognitive development: Behavioral and neural perspectives* (pp. 327–349). Mahwah, NJ: Erlbaum.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology*, *54*, 241–257.

Cassirer, E. (1953). *Substance and function*. New York, NY: Dover. (Original work published 1923)

Cassotti, M., Houdé, O., & Moutier, S. (2011). Developmental changes of win-stay and loss-shift strategies in decision making. *Child Neuropsychology*, *17*, 400–411.

Catale, C., Willems, S., Lejeune, C., & Meulemans, T. (2012). Parental educational level Influence on memory and executive performance in children. *Revue Européenne de Psychologie Appliquée*, *62*, 161–171.

Cepeda, N. J., Kramer, A. F., & Gonzalez de Sather, J. C. M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology*, *37*, 715–730.

Chatham, C. H., Frank, M. J., & Munakata, Y. (2009). Pupillometric and behavioral markers of a developmental shift in the temporal dynamics of cognitive control. *Proceedings of the National Academy of Sciences, USA*, *106*, 5529–5533.

Chevalier, N., & Blaye, A. (2008). Cognitive flexibility in preschoolers: The role of representation activation and maintenance. *Developmental Science*, *11*, 339–353.

Chugani, H. T., Phelps, M. E. & Mazziotta, J. C. (1987). Positron emission tomography study of human brain functional development, *Annals of Neurology*, *22*, 487–497.

Clark, C. A., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology*, *46*, 1176–1191.

Clark, L., Bechara, A., Damasio, H., Aitken, M. R. F., Sahakian, B. J., & Robbins, T. W. (2008). Differential effects of insular and ventromedial prefrontal cortex lesions on risky decision-making. *Brain*, *131*, 1311–1322.

Cole, M. W. & Schneider, W. (2007). The cognitive control network: Integrated cortical regions with dissociable functions. *NeuroImage*, *37*, 343–360.

Cole, M. W., Pathak, S. & Schneider, W. (2010). Identifying the brain's most globally connected regions. *NeuroImage*, *49*, 3132–3148.

Conklin, H. M., Luciana, M., Hooper, C. J., & Yarger, R. S. (2007). Working memory performance in typically developing children and adolescents: Behavioral evidence of protracted frontal lobe development. *Developmental Neuropsychology*, *31*, 103–128.

Conway, A., & Stifter, C. A. (2012). Longitudinal antecedents of executive function in preschoolers. *Child Development*, *83*, 1022–1036.

Cowan, N. (2005). *Working memory capacity*. Hove, England: Psychology Press.

Cragg, L., & Chevalier, N. (2012). The processes underlying flexibility in childhood. *The Quarterly Journal of Experimental Psychology*, *65*, 209–332.

Cragg, L., & Nation, K. (2008). Go or no-go? Developmental improvements in the efficiency of response inhibition in mid-childhood. *Developmental Science*, *11*, 819–827.

Crone, E. A., Bunge, S. A., van der Molen, M. W., & Ridderinkhof, K. R. (2006). Switching between tasks and responses: A developmental study. *Developmental Science*, *9*, 278–287.

Crone, E. A., Donohue, S. E., Honomichl, R., Wendelken, C., & Bunge, S. A. (2006). Brain regions mediating flexible rule use during development. *Journal of Neuroscience*, *26*, 11239–11247.

Crone, E. A., Ridderinkhof, K. R., Worm, M., Somsen, R. J. M., & van der Molen, M. W. (2004). Switching between spatial stimulus–response mappings: A developmental study of cognitive flexibility. *Developmental Science 7*, 443–455.

Crone, E. A, & van der Molen, M. W. (2004). Developmental changes in real life decision making: Performance on the gambling task previously shown to depend on the vetromedial prefrontal cortex. *Developmental Neuropsychology*, *25*, 251–279.

Crone, E. A., Wendelken, C., Donohue, S., van Leijenhorst, L., & Bunge, S. A. (2006). Neurocognitive development of the ability to manipulate information in working memory. *Proceedings of the National Academy of Sciences, USA*, *103*, 9315–9320.

Cummings, J. L. (1993). Frontal-subcortical circuits and human behaviour. *Archives of Neurology*, *50*, 873–880.

Daigneault, S., Braun, C. M. J. & Montes, J. L. (1997). Pseudodepressive personality and mental interia in a child with a focal left-frontal lesion. *Developmental Neuropsychology*, *13*, 1–22.

Damasio, A. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York, NY: Grosset/Putnam.

Darki, F., & Klingberg, T. (2014). The role of fronto-patietal and fronto-striatal networks in the development of working memory: A longitudinal study. *Cerebral Cortex*. doi:10.1093/cercor/bht352

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*, 2037–2078.

Dehaene-Lambertz, G., Dehaene, S. & Hertz-Pannier, L. (2002). Functional neuroimaging of speech perception in infants. *Science*, *298*, 2013–2015.

Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45–75.

Dennis, M., Agostino, A., Roncadin, C., & Levin, H. (2009). Theory of mind depends on domain-general executive functions of working memory and cognitive inhibition in children with traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *13*, 835–847.

Devine, R. T., & Hughes, C. (2014). Relations between false-belief understanding and executive function in early childhood: A meta-analysis. *Child Development*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/cdev.12237/abstract

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science*, *21*, 335–341.

Diamond, A. (2013). Executive function. *Annual Review of Psychology*, *64*, 135–168.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*(5855), 1387–1388.

Diamond, A., Briand, L., Fossella, J., & Gehlbach, L. (2004). Genetic and neurochemical modulation of prefrontal cognitive functions in children. *American Journal of Psychiatry*, *161*, 125–132.

Diamond, A., Kirkham, N. Z., & Amso, D. (2002). Conditions under which young children can hold two rules in mind and inhibit a prepotent response. *Developmental Psychology*, *38*, 352–362.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*, 959–964.

Dick, A. S., & Overton, W. F. (2010). Executive function: Description and explanation. In B. F. Sokol, U. Müller, J. I. M. Carpendale, A. R. Young, & G. Iarocci (Eds.), *Self- and social regulation* (pp. 7–34). Oxford, England: Oxford University Press.

Dilworth-Bart, J., Poehlmann, J., Hilgendorf, A. E., Miller, K., & Lambert, H. (2010). Maternal scaffolding and preterm toddlers' visual-spatial processing and emerging working memory. *Journal of Pediatric Psychology*, *35*, 209–220.

Doria, V., Beckmann, C. F., Arichi, T., Merchant, N., Groppo, M., Turkheimer, F. E., . . . Edwards, A. D. (2010). Emergence of resting state networks in the preterm human brain. *Proceedings of the National Academy of Sciences, USA*, *107*, 20015–20020.

Dosenbach, N. U. F., Nardos, B., Cohen, A. L., Fair, D. A., Power, J. D., Church, J. A., . . . Schlaggar, B. L. (2010). Prediction of individual brain maturity using fMRI. *Science*, *329*, 1358–1361.

Dowsett, S. M., & Livesey, D. J. (2000). The development of inhibitory control in preschool children: Effects of "executive skills" training. *Developmental Psychobiology*, *36*, 161–174.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., . . . Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428–1446.

Dunn, B. D., Dalgleish, T., & Lawrence, A. D. (2006). The somatic marker hypothesis: A critical evaluation. *Neuroscience and Biobehavioral Reviews*, *30*, 239–271.

Durston, S. Davidson, M. C., Tottenham, N., Galvan, A., Spicer, J., . . . Casey, B. J. (2006). A shift from diffuse to focal activity with development. *Developmental Science*, *9*, 1–20.

Duveen, G., & Psaltis, C. (2008). The constructive role of asymmetry in social interaction. In U. Müller, J. I. M. Carpendale, N. Budwig, & B. Sokol (Eds.), *Social life and social knowledge* (pp. 183–204). New York, NY: Erlbaum.

Edin, F., Macoveanu, J., Olesen, P. J., Tegnér, J., & Klingberg, T. (2007). Stronger synaptic connectivity as a mechanism behind development of working memory-related brain activity during childhood. *Journal of Cognitive Neuroscience*, *19*, 750–760.

Engle, R. W. (2002). Working memory as executive attention. *Current Directions in Psychological Science*, *11*, 19–23.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. *The Psychology of Learning and Motivation*, *44*, 145–198.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143–149.

Eslinger, P. J. (1996). Conceptualizing, describing and measuring components of executive function: A summary. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 367–395). Baltimore, MD: Brookes.

Eslinger, P. J., & Biddle, K. R. (2000). Adolescent neuropsychological development after early right prefrontal cortex damage. *Developmental Neuropsychology*, *18*, 297–329.

Eslinger, P. J., & Geder, L. (2000). Behavioral and emotional changes after focal frontal lobe damage. In J. Bogousslavsky & J. L. Cummings (Eds.), *Behavior and mood disorders in focal brain lesions* (pp. 217–260). Cambridge, England: Cambridge University Press.

Eslinger, P. J., Flaherty-Craig, C. V., & Benton, A. L. (2004). Developmental outcomes after early prefrontal cortex damage. *Brain and Cognition*, *55*, 84–103.

Espy, K. A., Kaufmann, P. M., McDiarmid, M. D., & Glisky, M. L. (1999). Executive functioning in preschool children: Performance on A-not-B and other delayed response format tasks. *Brain and Cognition*, *41*, 178–199.

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, E., & Senn, T. E. (2004). The contribution of executive functions to emerging mathematic skills in preschool children. *Developmental Neuropsychology*, *26*, 465–486.

Ezekiel, F., Bosma, R., & Morton, J. B. (2013). Dimensional Change Card Sort performance associated with age-related differences in functional connectivity of lateral prefrontal cortex. *Developmental Cognitive Neuroscience*, *5*, 40–50.

Fair, D. A., Cohen, A. L., Power, J. D., Dosenbach, N. U. F., Church, J. A., Miezin, F. M., . . . Petersen, S. E. (2009). Functional brain networks develop from a "local to distributed" organization. *PLoS Computational Biology*, *5*, 1–14.

Fair, D. A., Dosenbach, N. U. F., Church, J. A., Cohen, A. L., & Brahmbhatt, S. (2007). Development of distinct control net- works through segregation and integration. *Proceedings of the National Academy of Sciences, USA*, *104*, 13507–13512.

Fatzer, S. T., & Roebers, C. M. (2012). Language and executive functions: The effect of articulatory suppression on executive functioning in children. *Journal of Cognition and Development*, *13*, 454–472.

Fernyhough, C., & Fradley, E. (2005). Private speech on an executive task: Relations with task difficulty and task performance. *Cognitive Development*, *20*, 103–120.

Fingelkurts, A. A., & Kahkonen, S. (2005). Functional connectivity in the brain—is it an elusive concept? *Neuroscience and Biobehavioral Reviews*, *28*, 827–836.

Fisher, A. V. (2011). Automatic shifts of attention in the Dimensional Change Card Sort task: Subtle changes in task materials lead to flexible switching. *Journal of Experimental Child Psychology*, *108*, 211–219.

Flynn, E. (2007). The role of inhibitory control in false belief understanding. *Infant and Child Development*, *16*, 53–69.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General*, *133*, 101–135.

Friedman, N. P., Miyake, A., Robinson, J. L., & Hewitt, J. K. (2011). Developmental trajectories in toddlers' self-restraint predict individual differences in executive functions 14 years later: A behavioral genetic analysis. *Developmental Psychology*, *47*, 1410–1430.

Friedman, N. P., Miyake, A., Young, S. E., DeFries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology General*, *137*, 201–225.

Friston, K. (2002). Beyond phrenology: What can neuroimaging tell us about distributed circuitry? *Annual Review of Neuroscience*, *25*, 221–250.

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology*, *54*, 1–34.

Frye, D., Zelazo, P. D., & Burack, J. A. (1998). I. Cognitive complexity and control: Implications for theory of mind in typical and atypical development. *Current Directions in Psychological Science*, *7*, 116–121.

Frye, D., Zelazo, P. D., & Palfai, T. (1995). Theory of mind and rule-based reasoning. *Cognitive Development*, *10*, 483–527.

Fuhs, M. W., & Day, J. D. (2011). Verbal ability and executive functioning development in preschoolers at Head Start. *Developmental Psychology*, *47*, 404–416.

Fuster, J. M. (1993). Frontal lobes. *Current Opinion in Neurobiology*, *3*(2), 160–165.

Fuster, J. M. (2002). Frontal lobe and cognitive development. *Journal of Neurocytology*, *31*, 373–385.

Fuster, J. M. (2008). *The prefrontal cortex* (4th ed.). San Diego, CA: Academic Press.

Gaillard, W. D., Hertz–Pannier, L., Mott, S. H., Barnett, A. S., LeBihan, D., & Theodore, W. H. (2000). Functional anatomy of cognitive development: fMRI of verbal fluency in children and adults, *Neurology*, *54*, 180.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*, 31–60.

Garon, N., & Moore, C. (2004). Complex decision-making in early childhood. *Brain and Cognition*, *55*, 158–170.

Garon, N., Smith, I. M., & Bryson, S. E. (2014). A novel executive function battery for preschoolers: Sensitivity to age differences. *Child Neuropsychology*. doi:10.1080/09297049.2013.857650

Garrett, H. E. (1946). A developmental theory of intelligence. *American Psychologist*, *1*, 372–378.

Gathercole, S. E., Brown, L., & Pickering, L. J. (2003). Working memory assessments at school entry as longitudinal predictors of National Curriculum attainment levels. *Educational and Child Psychology*, *20*, 109–121.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, *40*, 177–190.

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (1998). *Cognitive neuroscience: The biology of the mind*. New York, NY: Norton.

Gerstadt, C., Hong, Y., & Diamond, A. (1994). The relationship between cognition and action: performance on children 3 1/2–7 years old on a Stroop-like day-night test. *Cognition*, *53*, 129–153.

Godinez, D. A., Friedman, N. P., Rhee, S. H., Miyake, A., & Hewitt, J. K. (2012). Phenotypic and genetic analyses of the Wisconsin Card Sort. *Behavior Genetics*, *42*, 209–220.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., . . . Thompson, P. L. (2004). Dynamic mapping of human cortical development during childhood and adolescence. *Proceedings of the National Academy of Sciences, USA*, *101*, 8174–8179.

Gioia, G., Isquith, P. K., Guy, S. C., & Kenworthy, L. (2000). *Behavior Rating Inventory of Executive Function*. Odessa, FL: Psychological Assessment Resources.

Golden, C. J. (1981). The Luria-Nebraska children's battery: Theory and formulation. In G. W. Hynd & J. E. Obrzut (Eds.), *Neuropsychological assessment and the school-aged child* (pp. 277–302). New York, NY: Grune & Stratton.

Goldman-Rakic, P. S. (1987). Development of cortical circuitry and cognitive function. *Child Development*, *58*, 601–622.

Goldstein, K. (1944). The mental changes due to frontal lobe damage. *Journal of Psychology*, *17*, 187–208.

Goldstein, K., & Scheerer, M. (1941). Abstract and concrete behavior an experimental study with special tests. *Psychological Monographs*, *53*, 1–151.

Gordon, A. C. L., & Olson, D. R. (1998). The relation between acquisition of a theory of mind and the capacity to hold in mind. *Journal of Experimental Child Psychology*, *68*, 70–83.

Gorsuch, R. L. (1997). Exploratory factor analysis: Its role in item analysis. *Journal of Personality Assessment*, *68*, 532–560.

Gottlieb, G. (2003). On making behavioral genetics truly developmental. *Human Development*, *46*, 337–355.

Gottlieb, G. (2007). Probabilistic epigenesis. *Developmental Science*, *10*, 1–11.

Grant, D. A. & Berg, E. A. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology*, *38*, 404–411.

Grattan, L. M., & Eslinger, P. J. (1992). Long-term psychological consequences of childhood frontal lobe lesion in patient DT. *Brain and Cognition*, *20*, 185–195.

Greenberg, M. T., Kusche, C. A., Cook, E. T., & Quamma, J. P. (1995). Promoting emotional competence in school-aged children: The effects of the PATHS curriculum. *Development and Psychopathology*, *7*, 117–136.

Grossmann, K., Grossmann, K. E., Fremmer-Bombik, E., Kindler, H., Scheuerer-Englisch, H., & Zimmermann, P. (2002). The uniqueness of the child–father attachment relationship: Fathers' sensitive and challenging play as a pivotal variable in a 16-year longitudinal study. *Social Development*, *11*, 301–337.

Hackman, D. A., Farah, M. J., & Meaney, M. J. (2010). Socioeconomic status and the brain: Mechanistic insights from human and animal research. *Nature Reviews Neuroscience*, *11*, 651–659.

Hala, S., Hug, S., & Henderson, A. (2003). Executive functioning and false belief understanding in preschool children: Two tasks are harder than one. *Journal of Cognition and Development*, *4*, 275–298.

Hammond, S. I., Müller, U., Carpendale, J. I. M., Bibok, M. B., & Liebermann-Finestone, D. P. (2012). The effects of parental scaffolding on preschoolers' executive function. *Developmental Psychology*, *48*, 271–281.

Hanania, R. (2010). Two types of perseveration in the Dimension Change Card Sort task. *Journal of Experimental Child Psychology*, *107*, 325–326.

Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *Publications of the Massachusetts Medical Society*, *2*, 327–347.

Harnishfeger, K. K. (1995). The development of cognitive inhibition. Theories, definitions, and research evidence. In F. N. Dempster & C. J. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 175–204). San Diego, CA: Academic Press.

Henning, A., Spinath, F. M. & Aschersleben, G. (2011). The link between preschoolers' executive function and theory of mind and the role of epistemic states. *Journal of Experimental Psychology*, *108*, 513–531.

Henry, L. A., Messer, D., Luger-Klein, S., & Crane, L. (2012). Phonological, visual, and semantic coding strategies and children's short-term picture memory span. *Quarterly Journal of Experimental Psychology*, *65*, 2033–2053.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for plasticity of executive control processes. *Psychonomic Bulletin & Review*, *18*, 625–658.

Hitch, G. J., Halliday, M. S., Dodd, A., & Littler, J. E. (1989). Development of rehearsal in short-term memory: Differences between pictorial and spoken stimuli. *British Journal of Developmental Psychology*, *7*, 347–353.

Hofmann, W., Schmeichel, B. J., & Baddeley, A. D. (2012). Executive functions and self-regulation. *Trends in Cognitive Sciences*, *6*, 174–180.

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, *12*, F9–F15.

Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, *109*, 679–709.

Hongwanishkul, D., Happaney, K. R., Lee, W., & Zelazo, P. D. (2005). Hot and cool executive function: Age-related changes and individual differences. *Developmental Neuropsychology*, *28*, 617–644.

Howard, S. J., Johnson, J., & Pascual-Leone, J. (2014). Clarifying inhibitory control: Diversity and development of attentional inhibition. *Cognitive Development*, *31*, 1–21.

Hughes, C. (1998). Finding your marbles: Does preschoolers' strategic behavior predict later understanding of mind? *Developmental Psychology*, *34*, 1326–1339.

Hughes, C., & Ensor, R. (2007). Executive function and theory of mind: Predictive relations from ages 2 to 4. *Developmental Psychology*, *43*, 1447–1459.

Hughes, C., & Ensor, R. A. (2009). How do families help or hinder the emergence of early executive function? In C. Lewis & J. I. M. Carpendale (Eds.), *Social interaction and the development of executive function. New directions in child and adolescent development* (No. 123, pp. 35–50). San Francisco, CA: Jossey-Bass.

Hughes, C., Ensor, R., Wilson, A., & Graham, A. (2010). Tracking executive function across the transition to school: A latent variable approach. *Developmental Neuropsychology*, *35*, 20–36.

Hughes, C., & Graham, A. (2002). Measuring executive functions in childhood: Problems and solutions? *Child and Adolescent Mental Health*, *7*, 131–142.

Huizenga, H. M., & Crone, E. A., & Jansen, B. J. (2007). Decision-making in healthy children, adolescents and adults explained by the use of increasingly complex proportional reasoning rules. *Developmental Science 10*, 814–825.

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variable analysis. *Neuropsychologia*, *44*, 2017–2036.

Huizinga, M., & van der Molen, M. (2007). Age-group differences in set-switching and set-maintenance on the Wisconsin Card Sorting Task. *Developmental Neuropsychology*, *31*, 193–215.

Hull, C. L. (1920). Quantitative aspects of the evolution of concepts. *Psychological Monographs*, *28* (Whole No. 123).

Hunter, W. S. (1913). The delayed reaction in animals and children. *Behavior Monographs*, *2*, 1–86.

Husserl, E. (1970). *Logical investigations*. London: Routledge. (Original work published 1900/1901)

Huttenlocher, P. R. (1979). Synaptic density in human frontal cortex-developmental changes and effects of aging. *Brain Research*, *163*, 195–205.

Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *Journal of Comparative Neurology*, *387*, 167–178.

Hwang, K., Velanova, K., & Luna, B. (2010). Strengthening of top-down frontal cognitive control networks underlying the development of inhibitory control: A functional magnetic resonance imaging effective connectivity study. *Journal of Neuroscience*, *30*, 1535–1545.

Ionescu, T. (2012). Exploring the nature of cognitive flexibility. *New Ideas in Psychology*, *30*, 190–200.

Jacobs, R., Harvey, A. S., & Anderson, V. (2011). Are executive skills primarily mediated by the prefrontal cortex in childhood? Examination of focal brain lesions in childhood. *Cortex*, *47*, 808–824.

Jacobsen, C. F. (1936). Studies of cerebral function in primates: I. The functions of the frontal association areas in monkeys. *Comparative Psychology Monographs*, *13*, 1–68.

Jacques, S., & Marcovitch, S. (2010). Development of executive function across the lifespan. In W. F. Overton (Ed.), *Cognition, biology, and methods*. Volume 1 of *The handbook of life-span development* (pp. 431–466). Editor-in-Chief: R. M. Lerner. Hoboken, NJ: Wiley.

Jacques, S., & Zelazo, P. D. (2005). On the possible socio-communicative roots of cognitive flexibility. In B. Homer & C. Tamis-Lemonda (Eds.), *The development of social understanding and communication* (pp. 53–81). Mahwah, NJ: Erlbaum.

Jacques, S., Zelazo, P. D., Kirkham, N. Z., & Sencesen, T. K. (1999). Rule selection and rule execution in preschoolers: An error-detection approach. *Developmental Psychology*, *35*, 770–780.

Jarrold, C., & Hall, D. (2013). The development of rehearsal in verbal short-term memory. *Child Development Perspectives*, *7*, 182–186.

Jernigan, T. L., & Tallal, P. (1990). Late childhood changes in brain morphology observable with MRI. *Developmental Medicine & Child Neurology*, *32*, 1469–8749.

Johnson, M. H., & Munakata, Y. (2005). Processes of change in brain and cognitive development. *Trends in Cognitive Science*, *9*, 152–158.

Johnstone, S. J., Dminoska, A., Smith, J. L., Barry, R. J., Pleffer, C. B., Chiswick, D., & Clarke, A. R. (2007). The development of stop-signal and Go/Nogo response inhibition in children aged 7–12 years: Performance and event-related potential indices. *International Journal of Psychophysiology*, *63*, 25–38.

Jolles, D. D., Kleibeuker, S. W., Rombouts, S. A. R. B., & Crone, E. A. (2011). Developmental differences in prefrontal activation during working memory maintenance and manipulation for different memory loads. *Developmental Science*, *14*, 713–724.

Jones, L. B., Rothbart, M. K., & Posner, M. I. (2003). Development of executive attention in preschool children. *Developmental Science*, *6*, 498–504.

Jordan, P. L., & Morton, J. B. (2008). Flankers facilitate 3-year-olds performance in a card- sorting task. *Developmental Psychology*, *44*, 265–274.

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychological Review*, *17*, 213–233.

Kabat-Zinn, J. (2003). Mindfulness-based interventions in context: Past, present, and future. *Clinical Psychology: Science and Practice*, *10*, 144–156.

Kaller, C., Rahm, B., Spreer, J., Mader, I., & Unterrainer, J. M. (2008). Thinking around the corner: The development of planning abilities. *Brain and Cognition*, *67*, 360–370.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, *9*, 637–671.

Karbach, J., & Kray, J. (2007). Developmental changes in switching between mental sets: The influence of verbal labeling in childhood. *Journal of Cognition and Development*, *8*, 205–236.

Karbach, J., Kray, J., & Hommel, B. (2011). Action-effect learning in early childhood: Does language matter? *Psychological Research*, *75*, 334–340.

Keren, G., & Schul, Y. (2009). Two is not always better than one: A critical evaluation of two-system theories. *Perspectives on Psychological Science*, *4*, 533–550.

Kerns, K. A., MacSween, J. Vander Weeken, S., & Grupposo, V. (2010). Investigating the efficacy of an attention training programme in children with foetal alcohol spectrum disorder. *Developmental Neurorehabilitation*, *13*, 413–422.

Kerr, A., & Zelazo, P. D. (2004). Development of "hot" executive function: The Children's Gambling Task. *Brain and Cognition*, *55*, 148–157.

Kim, S., & Kochanska, G. (2012). Child temperament moderates effects of parent–child mutuality on self-regulation: A relationship-based path for emotionally negative infants. *Child Development*, *83*, 1275–1289.

Kirkham, N. Z., Cruess, L. M., & Diamond, A. (2003). Helping children apply their knowledge to their behavior on a dimension-switching task. *Developmental Science*, *6*, 449–467.

Kishiyama, M. M., Boyce, T. W., Jimenez, A. M., Perry, L. M., & Knight, R. T. (2008). Socioeconomic disparities affect prefrontal function in children. *Journal of Cognitive Neuroscience*, *21*, 1106–1115.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, *24*, 781–791.

Kloo, D., & Perner, J. (2003). Training transfer between card sorting and false belief understanding: Helping children apply conflicting descriptions. *Child Development*, *74*, 1823–1839.

Kloo, D., Perner, J., & Giritzer, T. (2010). Object-based set shifting in preschoolers: Relations to theory of mind. In B. W. Sokol, U. Müller, J. I. M. Carpendale, A. R. Young, & G. Iarocci (Eds.), *Self- and social regulation* (pp. 193–217). Oxford, England: Oxford University Press.

Knight, R. T., & D'Esposito, M. (2003). Lateral prefrontal syndrome: A disorder of executive control. In M. D'Esposito (Ed.), *Neurological foundations of cognitive neuroscience* (pp. 259–279). Cambridge, MA: MIT Press.

Kochanska, G., Murray, K. T., & Harlan, E. T. (2000). Effortful control in early childhood: Continuity and change, antecedents, and implications for social development. *Developmental Psychology*, *36*, 220–232.

Kochanska, G., Murray, K. T., Jacques, T. Y., Koenig, A. L., & Vandegeest, K. A. (1996). Inhibitory control in young children and its role in emerging internalization. *Developmental Psychology*, *36*, 220–232.

Koechlin, E., & Summerfield, C. (2007). An information theoretical approach to prefrontal executive function. *Trends in Cognitive Sciences*, *11*, 229–235.

Kok, R., Lucassen, N., Bakermans-Kranenburg, M. J., van IJzendoorn, M. H., Ghassabian, A., Roza, S. J., . . . Tiemeier, H. (2013). Parenting, corpus callosum, and executive function in preschool children. *Child Neuropsychology*. Available at http://dx.doi.org/10.1080/09297049.2013.832741

Kolb, B. (1984). Functions of the frontal cortex of the rat: A comparative review. *Brain Research Reviews*, *8*, 65–98.

Kolb, B., & Fantie, B. (1989). Development of the child's brain and behaviour. In C. R. Reynolds & E. Fletcher-Janzen (Eds.), *Handbook of clinical child psychology* (pp. 17–39). New York, NY: Plenum Press.

Kolb, B., Mychasiuk, R., Muhammad, A., Li, Y., Frost, D. O., & Gibb, R. (2012). Experience and the developing prefrontal cortex. *Proceedings of the National Academy of Sciences, USA*, *109*(Suppl. 2), 17186–17193.

Kopp, C. B. (1982). Antecedents of self-regulation: A developmental perspective. *Developmental Psychology*, *18*, 199–214.

Kray, J., Eber, J., & Karbach, J. (2008). Verbal self-instruction in task switching: A compensatory tool for action-control deficits in childhood and old age? *Developmental Science*, *11*, 223–236.

Kray, J., Eenhuistra, R. M., Kerstner, H., Weidema, M., & Hommel, B. (2006). Language and action control: The acquisition of action goals in early childhood. *Psychological Science*, *17*, 737–741.

Kray, J., & Ferdinand, N. K. (2013). How to improve cognitive control in development during childhood: Potentials and limits of cognitive interventions. *Child Development Perspectives*, *7*, 121–125.

Kray, J., Kipp, K., & Karbach, J. (2009). The development of selective inhibitory control: The influence of verbal labeling. *Acta Psychologica*, *130*, 48–57.

Kuntsi, J., Stevenson, J., Osterlaan, J., & Sonuga-Barke, E. J. S. (2001). Test-retest reliability of a new delay aversion task and executive function measures. *British Journal of Developmental Psychology*, *19*, 339–348.

Landry, S. H., Miller-Loncar, C. L., Smith, K. E., & Swank, P. R. (2002). The early parenting in children's development of executive processes. *Developmental Neuropsychology*, *21*, 15–41.

Lawson, G. M., Duda, J. T., Avants, B. B., Wu, J., & Farah, M. J. (2013). Associations between children's socioeconomic status and prefrontal cortical thickness. *Developmental Science*, *16*, 641–652.

Lee, K., Bull, R., & Ho, R. M. H. (2013). Developmental changes in executive functioning. *Child Development*, *84*, 1933–1953.

Lee, K., Ng, S. F., Pe, M. L., Ang, S. Y., Hasshim, M. N. A. M., & Bull, R. (2012). The cognitive underpinnings of emerging mathematical skills: Executive functioning, patterns, numeracy, and arithmetic. *British Journal of Educational Psychology*, *82*, 82–99.

Lehmann, M., & Hasselhorn, M. (2007). Variable memory strategy use in children adapted into a task learning behavior: Developmental changes and working memory influences in free recall. *Child Development*, *78*, 1068–1082.

Lehto, J. E., Juujärvi, P., Kooistra, L., & Pulkkinen, L. (2003). Dimensions of executive functioning: Evidence from children. *British Journal of Developmental Psychology*, *21*, 59–80.

Lerner, R. M. (2011). Structure and process in relational developmental systems theories: A commentary on contemporary changes in the understanding of developmental change across the life-span. *Human Development*, *54*, 34–43.

Lerner, R. M., & Overton, W. F. (2008). Exemplifying the integrations of the relational developmental system: Synthesizing theory, research, and application to promote positive development and social justice. *Journal of Adolescent Research*, *23*, 245–255.

Leslie, A. M., & Polizzi, P. (1998). Inhibitory processing in the false belief task: Two conjectures. *Developmental Science*, *1*, 247–253.

Lewis-Morrarty, E., Dozier, M., Bernard, K., Terracciano, S. M., & Moore, S. V. (2012). Cognitive flexibility and theory of mind outcomes among foster children: Preschool follow-up results of a randomized clinical trial. *Journal of Adolescent Health*, *51*, S17–S22.

Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4th ed.). New York, NY: Oxford University Press.

Lidstone, J. S. M., Meins, E., & Fernyhough, C. (2010). The roles of private speech and inner speech in planning during middle childhood: Evidence from a dual task paradigm. *Journal of Experimental Child Psychology*, *107*, 438–451.

Liebermann, D., Giesbrecht, G. F., & Müller, U. (2007). Cognitive and emotional aspects of self- regulation in preschoolers. *Cognitive Development*, *22*, 511–529.

Liew, J. (2011). Effortful control, executive functions, and education: Bringing self-regulatory and social-emotional competencies to the table. *Child Development Perspectives*, *5*, 1–7.

Lillard, A. S. (2012). Preschool children's development in classic Montessori, supplemented Montessori, and conventional programs. *Journal of School Psychology*, *50*, 379–401.

Lillard, A. S., & Else-Quest, N. (2006). The early years: Evaluating Montessori education. *Science*, *313*(5795), 1893–1894.

Lillard, A. S., Lerner, M. D., Hopkins, E. J., Dore, R. A., Smith, E. D., & Palmquist, C. M. (2012). The impact of pretend play on children's development: A review of the evidence. *Psychological Bulletin*, *139*, 1–34.

Lipina, S., Segretin, S., Hermida, J., Prats, L., Fracchia, C., Camelo, J. L., & Colombo, J. (2013). Linking childhood poverty and cognition: Environmental mediators of non-verbal executive control in an Argentine sample. *Developmental Science*, *16*, 697–707.

Liston, C., Watts, R., Tottenham, N., Davidson, M. C., Niogi, S., Ulug, A. M., & Casey, B. J. (2006). Frontostriatal microstructure modulates efficient recruitment of cognitive control. *Cerebral Cortex*, *16*, 553–560.

Logan, G. D. (1988). Toward an instance theory of automatization. *Psychological Review*, *95*, 492–527.

Logan, G. D., & Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit thought and action: A model and a method. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 276–291.

Loosli, S. V., Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory training improves reading processes in typically developing children. *Child Neuropsychology*, *18*, 62–78.

Lorsbach, T. C., & Reimer, J. F. (2010). Developmental differences in cognitive control: Goal representation and maintenance during a continuous performance task. *Journal of Cognition and Development*, *11*, 185–216.

Luciana, M., Collins, P. F., Olson, E. A., & Schissel, A. M. (2009). Tower of London performance in healthy adolescents: The development of planning skills and associations with self-reported inattention and impulsivity. *Developmental Neuropsychology*, *34*, 461–475.

Luciana, M., Conklin, H. M., Hooper, C. J., & Yarger, R. S. (2005). The development of nonverbal working memory and executive control processes in adolescents. *Child Development*, *76*, 697–712.

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development*, *75*, 1357–1372.

Luria, A. R. (1959). The directive function of speech in development and dissolution, part I. *Word*, *15*, 341–352.

Luria, A. R. (1961). *The role of speech in the regulation of normal and abnormal behaviour* (J. Tizard, Ed.). New York, NY: Pergamon Press.

Luria, A. R. (1966). *Higher cortical functions in man*. New York, NY: Basic Books.

Luria, A. R. (1973). The working brain: An introduction to neuropsychology. New York, NY: Basic Books.

Lyons, K. E., & Zelazo, P. D. (2011). Monitoring, metacognition, and executive function: Elucidating the role of self-reflection in the development of self-regulation. In J. B. Benson (Ed.), *Advances in child development and behavior* (Vol. 40, pp. 379–412). London, England: Elsevier.

Mackey, A. P., Raizada, R. D. S., & Bunge, S. A. (2013). Environmental influences on prefrontal development. In In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (2nd ed., pp. 145–163). New York, NY: Oxford University Press.

Macdonald, J. A., Beauchamp, M. H., Crigan, J. A., & Anderson, P. J. (2014). Age-related differences in inhibitory control in the early school years, *Child Neuropsychology*, *20*, 509–526.

MacLeod, C. M. (2007). The conception of inhibition in cognition. In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 3–23). Washington, DC: American Psychological Association.

MacLeod, C. M., Dodd, M. D., Sheard, E. D., Wilson, D. E., & Bibi, U. (2003). In opposition to inhibition. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, 163–214). San Diego, CA: Academic Press.

Macmillan, M. (1992). Inhibition and the control of behaviour: From Gall to Freud via Phineas Gage and the frontal lobes. *Brain and Cognition*, *19*, 72–104.

Macmillan, M. (2000). *An odd kind of fame: Stories of Phineas Gage*. Cambridge, MA: MIT Press.

Marcovitch, S., Boseovski, J., & Knapp, R. J. (2007). Use it or lose it: Examining preschoolers' difficulty in maintaining and executing a goal. *Developmental Science*, *10*, 559–564.

Marcovitch, S., & Zelazo, P. D. (2009). A hierarchical competing systems model of the emergence and early development of executive function. *Developmental Science*, *12*, 1–18.

Martin, J., & Failows, L. (2010). Executive functions: theoretical concerns. In B. F. Sokol, U. Müller, J. I. M. Carpendale, A. R. Young, & G. Iarocci (Eds.), *Self- and social regulation* (pp. 35–55). Oxford, England: Oxford University Press.

Matte-Gagné, C., & Bernier, A. (2011). Prospective relations between maternal autonomy support and child executive functioning: Investigating the mediating role of child language ability. *Journal of Experimental Child Psychology*, *110*, 611–625.

McAlister, A. R., & Peterson, C. C. (2013). Siblings, theory of mind, and executive functioning in children aged 3–6 years: New longitudinal evidence. *Child Development*, *84*, 1442–1458.

McAuley, T., Christ, S. E., & White, D. A. (2011). Mapping the development of response inhibition in young children using a modified day-night task. *Developmental Neuropsychology*, *36*, 539–551.

McAuley, T., & White, D. A. (2011). A latent variables examination of processing speed, response inhibition, and working memory during typical development. *Journal of Experimental Psychology*, *108*, 453–468.

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers' literacy, vocabulary, and math skills. *Developmental Psychology*, *43*, 947–959.

McCormack, T., & Atance, C. M. (2011). Planning in young children: A review and synthesis. *Developmental Review*, *31*, 1–31.

McDermott, J. M., Pérez-Edgar, K., & Fox, N. A. (2007). Variations of the flanker paradigm: Assessing selective attention in young children. *Behavior Modification*, *39*, 62–70.

McDermott, J. M., Westerlund, A., Zeanah, C. H., Nelson, C. A., & Fox, N. F. (2012). Early adversity and neural correlates of executive function: Implications for academic adjustment. *Developmental Cognitive Neuroscience*, *25*, S59–S66.

Meaney, M. J. (2001). Nature, nurture, and the disunity of knowledge. *Annals of the New York Academy of Sciences*, *935*, 50–61.

Melby-Lervåg, M., & Hulme, C. (2012). Is working memory training effective? A meta-analytic review. *Developmental Psychology*, *2*, 270–291.

Meyer, M., Bekkering, H., Paulus, M., & Hunnius, S. (2010). Joint action coordination in 2½- and 3-year-old children. *Frontiers in Human Neuroscience*, *4*, 1–7. doi:10.3389/fnhum.2010.00220

Miller, M. R., Giesbrecht, G., Müller, U., McInerney, R., & Kerns, K. A. (2012). A latent variable approach to determining the structure of executive function in preschool children. *Journal of Cognition and Development*, *13*, 395–423.

Mischel, W., Shoda, Y., & Rodriguez, M. L. (1989, May 26). Delay of gratification in children. *Science*, *244*, 933–938.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science*, *8*, 8–14.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*, 49–100.

Monette, S., Bigras, M., & Guay, M.-C. (2011). The role of executive functions in school achievement at the end of Grade 1. *Journal of Experimental Child Psychology*, *109*, 158–173.

Monsell, S. (2003). Task switching. *Trends in Cognitive Sciences*, *7*, 134–140.

Montgomery, D. E., & Koeltzow, T. E. (2010). Review of the day-night task: The Stroop paradigm and interference control in young children. *Developmental Review*, *30*, 308–330.

Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*, 425–433.

Moriguchi, Y., Evans, A. D., Hiraki, K., Itakura, S., & Lee, K. (2012). Cultural differences in the development of cognitive shifting: East-West comparison. *Journal of Experimental Child Psychology*, *111*, 156–163.

Moriguchi, Y., & Hiraki, K. (2009). Neural origin of cognitive shifting in young children. *Proceedings of the National Academy of Sciences, USA*, *106*, 6017–6021.

Moriguchi, Y., & Hiraki, K. (2011). Longitudinal development of prefrontal function during early childhood. *Developmental Cognitive Neuroscience*, *1*, 153–162.

Moriguchi, Y., & Hiraki, K. (2014). Behavioral and neural differences during two versions of cognitive shifting tasks in young children and adults. *Developmental Psychobiology*, *56*, 761–769.

Morton, J. B. (2010). Understanding genetic, neurophysiological, and experiential influences on the development of executive functioning: The need for developmental models. *Wiley Interdisciplinary Reviews: Cognitive Science*, *1*, 709–723.

Morton, J. B., Bosma, R., & Ansari, D. (2009). Age-related changes in brain activation associated with dimensional shifts of attention: An fMRI study. *NeuroImage*, *46*, 249–256.

Morton, J. B., & Munakata, Y. (2002). Active vs. latent representations: A neural network model of perseveration, dissociation, and decalage. *Developmental Psychobiology*, *40*, 255–265.

Moses, L. J., & Carlson, S. M. (2004). Self-regulation and children's theories of mind. In M. Chandler, C. Lalonde, & C. Lightfoot (Eds.), *Changing conceptions of psychological life* (pp. 127–146). Mahwah, NJ: Erlbaum.

Moses, L. J., & Tahiroglu, D. (2010). Clarifying the relation between executive function and children's theories of mind. In B. W. Sokol, U. Müller, J. I. M. Carpendale, A. R. Young, & G. Iarocci (Eds.), *Self- and social regulation* (pp. 218–233). Oxford, England: Oxford University Press.

Müller, U., Baker, L., & Yeung, E. (2013). A developmental systems approach to executive function. In R. M. Lerner & J. B. Benson (Eds.), *Embodiment and epigenesis: Theoretical and methodological issues in understanding the role of biology within the relational developmental system. Part B—Ontogenetic dimensions*. *Advances in child development and behavior* (Vol. 45, pp. 39–66). London, England: Elsevier.

Müller, U., Dick, A. S., Gela, K., Overton, W. F., & Zelazo, P. D. (2006). The role of negative priming in preschoolers' flexible rule use on the dimensional change card sort task. *Child Development*, *77*, 395–412.

Müller, U., Jacques, S., Brocki, K., & Zelazo, P. D. (2009). In A. Winsler, C. Fernyhough, & I. Montero (Eds.), *Private speech, executive functioning, and the development of verbal self-regulation* (pp. 53–68). New York, NY: Cambridge University Press.

Müller, U., Kerns, K. A., & Konkin, K. (2012). Test–retest reliability and practice effects of executive function tasks in preschool children. *Clinical Neuropsychologist*, *26*, 271–287.

Müller, U., Liebermann, D. P., Frye, D., & Zelazo, P. D. (2008). Executive function, school readiness and school achievement. In S. K. Thurman & C. A. Fiorello (Eds.), *Applied cognitive research in K–3 classrooms* (pp. 41–83). New York, NY: Taylor & Francis.

Müller, U., Zelazo, P. D., Hood, S., Leone, T., & Rohrer, L. (2004). Interference control in a new rule use task: Age-related changes, labeling, and attention. *Child Development*, *75*, 1594–1609.

Müller, U., Zelazo, P. D., Lurye, L. E., & Liebermann, D. P. (2008). The effect of labeling on preschool children's performance in the Dimensional Change Card Sort Task. *Cognitive Development*, *23*, 395–408.

Munakata, Y. (1998). Infant perseveration: Rethinking data, theory, and the role of modelling. *Developmental Science*, *1*, 205–211.

Munakata, Y., Chatham, C. H., & Snyder, H. R. (2013). Mechanistic accounts of frontal lobe development. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (2nd ed., pp. 185–206). New York, NY: Oxford University Press.

Munakata, Y., Herd, S. A., Chatham, C. H., Depue, B. E., Banich, M. T., & O'Reilly, R. (2011). A unified framework for inhibitory control. *Trends in Cognitive Sciences*, *15*, 453–459.

Munakata, Y., Snyder, H. R., & Chatham, C. H. (2012). Developing cognitive control: Three key transitions. *Current Directions in Psychological Science*, *21*, 71–77.

Munakata, Y., & Yerys, B. E. (2001). All together now: When dissociations between knowledge and action disappear. *Psychological Science*, *12*, 335–337.

Nagy, Z., Westerberg, H. & Klingberg, T. (2004). Maturation of white matter is associated with the development of cognitive functions during childhood. *Journal of Cognitive Neuroscience*, *16*, 1227–1233.

Neumann, O. (1984). Automatic processing: A review of recent findings and a plea for an old theory. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 255–293). Berlin, Germany: Springer Verlag.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *12*, 220–246.

Noble, K. G., McCandliss, B. D., & Farah, M. J. (2007). Socioeconomic gradients predict Individual differences in neurocognitive abilities. *Developmental Science*, *10*, 464–480.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science*, *8*, 74–87.

Oh, S., & Lewis, C. (2008). Korean preschoolers' advanced inhibitory control and its relation to other executive skills and mental state understanding. *Child Development*, *79*, 80–99.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, *66*, 232–258.

Palmer, S. (2000). Working memory: A developmental study of phonological recoding. *Memory*, *8*, 179–193.

Pellicano, E. (2007). Links between theory of mind and executive function in young children with autism: Clues to developmental primacy. *Development and Psychopathology*, *17*, 47–65.

Pellicano, E. (2012). The development of executive function in autism. *Autism Research and Treatment, 2012*. http://dx.doi.org/10.1155/2012/146132

Pelphrey, K. A., & Reznick, J. S. (2003). Working memory in infancy. In R. V. Kail (Ed.), *Advances in child development and behavior* (Vol. 31, pp. 173–227). San Diego, CA: Academic Press.

Pelphrey, K. A., Reznick, J. S., Goldman, B. D., Sasson, N., Morrow, J., Donahoe, A., & Hodgson, K. (2004). Development of visuospatial short-term memory in the second half of the 1st year. *Developmental Psychology*, *40*, 836–851.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *37*, 51–87.

Pentland, L., Todd, J., & Anderson, V. (1998). The impact of head injury on planning ability in adolescence: A functional analysis. *Neuropsychological Rehabilitation*, *29*, 993–1006.

Perner, J. (1991). *Understanding the representational mind*. Cambridge, MA: MIT Press.

Perner, J., & Lang, B. (1999). Development of theory of mind and cognitive control. *Trends in Cognitive Sciences*, *3*, 337–344.

Perner, J., & Lang, B. (2000). Theory of mind and executive function: Is there a developmental relationship? In S. Baron-Cohen, H. Tager-Flusberg, & D. Cohen (Eds.), *Understanding others minds: Perspective from autism and developmental cognitive neuroscience*, (pp. 150–181). Oxford, England: Oxford University Press.

Perner, J., & Lang, B. (2002). What causes 3-year-olds' difficulty on the dimensional change card sorting task? *Infant and Child Development*, *11*, 93–105.

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Neuroscience*, *13*, 160–166.

Petanjek, Z., Judaš, M., Šimić, G., Rašin, M. R., Uylings, H. B. M, Rakic, P. & Kostović, I. (2011). Extraordinary neoteny of synaptic spines in the human prefrontal cortex *Proceedings of the National Academy of Sciences, USA*, *108*, 13281–13286.

Petanjek, Z., & Kostović, I. (2012). Epigenetic regulation of fetal brain development and neurocognitive outcome. *Proceedings of the National Academy of Sciences, USA*, *109*, 11062–11063.

Philips, L. H., Bull, R., Allen, R., Insch, P., Burr, K., & Ogg, W. (2011). Lifespan aging and belief reasoning: Influences of executive function and social cue decoding. *Cognition*, *120*, 236–247.

Piaget, J. (1963). *The origins of intelligence*. New York, NY: Norton. (Original work published 1936)

Piaget, J. (1976). *The grasp of consciousness*. Cambridge, MA: Harvard University Press. (Original work published 1974)

Piaget, J. (1985). *The equilibration of cognitive structures*. Chicago, IL: University of Chicago Press. (Original work published 1975)

Piaget, J. (2001). *Studies in reflecting abstraction*. Hove, UK: Psychology Press. (Original work published 1977)

Prencipe, A., Kesek, A., Cohen, J., Lamm, C., Lewis, M. D., & Zelazo, P. D. (2011). Development of hot and cool executive function during the transition to adolescence. *Journal of Experimental Child Psychology*, *108*, 621–637.

Pribram, K. H. (1973). The primate frontal cortex: Executive of the brain. In K. H. Pribram & A. R. Luria (Eds.), *Psychophysiology of the frontal lobes* (pp. 293–314). New York, NY: Academic Press.

Pribram, K. H. (1976). Executive functions of the frontal lobes. In T. Desiraju (Ed.), *Mechanis in transmission of signals for conscious behavior* (pp. 303–322). Amsterdam, The Netherlands: Elsevier.

Rabbitt, P. (1997). Introduction: Methodologies and models in the study of executive function. In P. Rabbitt (Ed.), *Methodology of frontal and executive function* (pp. 1–37). Hove, England: Psychology Press.

Redick, T. S., Heitz, R. P., & Engle, R. W. (2007). Working memory, capacity and inhibition: Cognitive and social consequences. In D. S. Gorfein & C. M. MacLeod (Eds.), *Inhibition in cognition* (pp. 125–142). Washington, DC: American Psychological Association.

Riggs, N. R., Greenberg, M. T., Kusche, C. A., & Pentz, M. A. (2006). The meditational role of neurocognition in the behavioral outcomes of a social–emotional prevention program in elementary school students: Effects of the PATHS curriculum. *Prevention Science*, *7*, 91–102.

Roberts, R. J., & Pennington, B. F. (1996). An interactive framework for examining prefrontal cognitive processes. *Developmental Neuropsychology*, *12*, 105–126.

Rolls, E. T., & Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology*, *86*, 216–244.

Romine, C. B., & Reynolds, C. R. (2005). A model of the development of frontal lobe functioning: Findings from a meta-analysis. *Applied Neuropsychology*, *12*, 190–201.

Roncadin, C., Pascual-Leone, J., Rich, J. B., & Denns, M. (2007). Developmental relations between working memory and inhibitory control. *Journal of the International Neuropsychological Society*, *13*, 59–67.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2011). Modeling a cascade of effects: The role of speed and executive functioning in preterm/full-term differences in academic achievement. *Developmental Science*, *14*, 1161–1175.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2012). Implications of infant cognition for executive function at age 11. *Psychological Science*, *23*, 1345–1355.

Rothbart, M. K., & Rueda, M. R. (2005). The development of effortful control. In U. Mayr, E. Awh, & S. W. Keele (Eds.), *Developing individuality in the human brain: A tribute to Michael I. Posner* (pp. 167–188). Washington, DC: American Psychological Association.

Rueda, M. R., Checa, P., & Cómbita, L. M. (2012). Enhanced efficiency of the executive attention network after training in preschool children: Immediate changes and effects after two months. *Developmental Cognitive Neuroscience*, *25*, S192–S204.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia*, *42*, 1029–1040.

Rushton, J. P., Brainerd, C. J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin*, *94*, 18–38.

Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). The development of executive functioning and theory of mind: A comparison of Chinese and U.S. preschoolers. *Psychological Science*, *17*, 74–81.

Sarsour, K., Sheridan, M., Jutte, D., Nuru-Jeter, A., Hinshaw, S., & Boyce, T. W. (2011). Family socioeconomic status and child executive functions: The roles of language, home environment, and single parenthood. *Journal of the International Neuropsychological Society*, *17*, 120–132.

Schelble, J. L., & Therriault, D. J., & Miller, M. D. (2012). Classifying retrieval strategies as a function of working memory. *Memory and Cognition*, *40*, 218–230.

Schmid, C., Zoelch, C., & Roebers, C. M. (2008). Das Arbeitsgedächtnis von 4- bis 5-jährigen Kindern: Theoretische und empirische Analyse seiner Funktionen. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie*, *40*, 2–12.

Schoemaker, K., Bunte, T., Wiebe, S. A., Espy, K. A., Deković, M., & Matthys, W. (2012). Executive function deficits in preschool children with ADHD and DBD. *Journal of Child Psychology and Psychiatry*, *53*, 111–119.

Senn, T. E., Espy, K. A., & Kaufmann, P. M. (2004). Using path analysis to understand executive function organization in preschool children. *Developmental Neuropsychology*, *26*, 445–464.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain*, *114*, 727–741.

Shing, Y. L., Lindenberger, U., Diamond, A., Li, S.-C., & Davidson, M. C. (2010). Memory maintenance and inhibitory control differentiate from early childhood to adolescence. *Developmental Neuropsychology*, *35*, 679–687.

Siklos, S., & Kerns, K. A. (2004). Assessing multitasking in children with ADHD using a modified Six Elements Test. *Archive of Clinical Neuropsychology*, *19*, 347–361.

Simpson, A., & Riggs, K. J. (2006). Conditions under which children experience inhibitory difficulty with a “button-press” go/no-go task. *Journal of Experimental Psychology*, *94*, 18–26.

Simpson, A., Riggs, K. J., Beck, S. R., Gorniak, S. L., Wu, Y., Abbott, D., & Diamond, A. (2012). Refining the understanding of inhibitory processes: How response prepotency is created and overcome. *Developmental Science*, *15*, 62–73.

Sinopoli, K. J., Schachar, R., & Dennis, M. (2011). Reward improves cancellation and restraint inhibition across childhood and adolescence. *Developmental Psychology*, *47*, 1479–1489.

Smidts, D. P., Jacobs, R., & Anderson, V. (2004). The object classification task for children (OXTC): A measure of concept generation and mental flexibility in early childhood. *Developmental Neuropsychology*, *26*, 385–401.

Snyder, H. R., & Munakata, Y. (2010). Becoming self-directed: Abstract representations support endogenous flexibility in children. *Cognition*, *116*, 155–167.

Sohlberg, M. M. & Mateer, C. A. (2001). *Cognitive rehabilitation: An integrative neuropsychological approach*. New York, NY: Guilford Press.

Sokolov, A. N. (1972). *Inner speech and thought*. New York, NY: Plenum Press.

Stevens, M. C. (2009). The developmental cognitive neuroscience of functional connectivity. *Brain Cognition*, *70*, 1–12.

Stevens, M. C., Kiehl, K. A., Pearlson, G. D., & Calhoun, V. D. (2007). Functional neural networks underlying response inhibition in adolescents and adults. *Behavior & Brain Research*, *181*, 12–22.

Sugarman, S. (1983). *Children’s early thought: Developments in classifications*. Cambridge, MA: Cambridge University Press.

Stuss, D. T., Levine, B., & Alexander, M. P. (2000). Wisconsin Card Sorting Test performance in patients with focal frontal and posterior brain damage: Effects of lesion location and test structure on separable cognitive processes. *Neuropsychologia*, *38*, 388–402.

Tang, Y. Y., Yang, L., Leve, L. D., & Harold, G. T. (2012). Improving executive function and Its neurobiological mechanisms through a mindfulness-based intervention: Advances within the field of developmental neuroscience. *Child Development Perspectives*, *6*, 361–364.

Thorell, L. B., Lindqvist, S., Bergman Nutley, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science*, *11*, 969–976.

Tomalski, P., Moore, D. G., Ribeiro, H., Axelsson, E. L., Murphy, E., Karmiloff-Smith, A., . . . Kushnerenko, E. (2013). Socioeconomic status and functional brain development—Associations in early infancy. *Developmental Science*, *16*, 676–687.

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: Do performance-based measures and ratings of executive function assess the same construct? *The Journal of Child Psychology and Psychiatry*, *54*(2), 131–143.

Tranel, D., Anderson, S. W., & Benton, A. (1994). Development of the concept of “executive function” and its relationship to the frontal lobes. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (Vol. 9, pp. 125–148). New York, NY: Elsevier.

Tsujimoto, S., Kuwajima, M., & Sawaguchi, T. (2007). Developmental fractionation of working memory and response inhibition during childhood. *Experimental Psychology*, *54*, 30–37.

Tulsky, D. S., Carlozzi, N. E., Chevalier, N., Espy, K. A., Beaumont, J. L., & Mungas, D. (2013). V. NIH Toolbox cognition battery (CB): Measuring working memory. *Monographs of the Society of Research in Child Development*, *78*, 70–87.

Tzourio-Mazoyer, N., De Schonen, S., Crivello, F., Reutter, B., Aujard, Y., & Mazoyer, B. (2002). Neural correlates of woman face processing by 2-month-old infants. *NeuroImage*, *15*, 454–461.

Urben, S., Van der Linden, M., & Barisnikov, K. (2011). Development of the ability to inhibit a prepotent response: Influence of working memory and processing speed. *British Journal of Developmental Psychology*, *29*, 981–998.

Usai, M. C., Viterbori, P., Traverso, L., & De Franchis, V. (2014). Latent structure of executive function in five- and six-year-old children: A longitudinal study. *European Journal of Developmental Psychology*, *11*, 447–462.

van den Bosch, G. E., El Marroun, H., Schmidt, M. N., Tibboel, D., Manoach, D. S., Calhoun, V. D., & White, T. J. H. (2014). Brain connectivity during verbal working memory in children and adolescents. *Human Brain Mapping*, *35*, 698–711.

van der Sluis, S., de Jong, P. F., & van der Leij, A. (2007). Executive functioning in children, and its relations with reasoning, reading, and arithmetic. *Intelligence*, *35*, 427–449.

Van der Ven, S. H. G., Kroesbergen, E. H., Boom, J., & Leseman, P. P. M. (2012). The development of executive functions and early mathematics: A dynamic relationship *British Journal of Educational Psychology*, *82*, 100–119.

Van der Ven, S. H. G., Kroesbergen, E. H., Boom, J., & Leseman, P. P. M. (2013). The structure of executive functions in children: A closer examination of inhibition, shifting, and updating. *British Journal of Developmental Psychology*, *31*, 70–87.

Vitiello, V. E., Greenfield, D. B., Munis, P., & George, J. (2011). Cognitive flexibility, approaches to learning, and academic school readiness in Head Start preschool children. *Early Education and Development*, *22*, 388–410.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1986). *Thought and language* (A. Kozulin, Trans.). Cambridge, MA: MIT Press. (Original work published 1934)

Vygotsky, L. S. (1997). Psychology and the theory of localization of mental functions. In R. W. Rieber & J. Wollock (Eds.), *The collected works of L. S. Vygotsky, Vol. 3: Problems of the theory and history of psychology* (pp. 139–144). New York, NY: Plenum Press. (Original work written in 1934)

Vygotsky, L. S., & Luria, A. (1994). Tool and symbol in child development. In R. van der Veer & J. Valsiner (Eds.), *The Vygotsky reader* (pp. 99–174). Oxford, England: Blackwell. (Original work published 1929)

Wass, S. V., Scerif, G., & Johnson, M. H. (2012). Training attentional control and working memory in memory—Is younger, better? *Developmental Review*, *32*, 360–387.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, *102*, 45–53.

Welsh, M. C. (1991). Rule-guided behavior and self-monitoring on the Tower of Hanoi disk-transfer task. *Cognitive Development*, *6*, 59–76.

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology*, *7*, 131–149.

Welsh, M. C. & Peterson, E. (2014). Issues in the conceptualization and assessment of hot executive functions in childhood. *Journal of the International Neuropsychological Society*, *20*, 152–156.

Welt, L. (1888). Ueber Charakterverȁnderungen des Menschen infolge von Lȁsionen des Stirnhirns. *Deutsches Archiv für Klinische Medicin*, *42*, 339–390.

Wendelken, C., Munakata, Y., Baym, C., Souza, M., & Bunge, S. A. (2012). Flexible rule use: common neural substrates in children and adults. *Developmental Cognitive Neuroscience 2*, 329–339.

Werner, H. (1957). The concept of development from a comparative and organismic point of view. In D. B. Harris (Ed.), *The concept of development: An issue in the study of human behaviour* (pp. 125–148). Minneapolis, MN: Jones Press.

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children: I. Latent structure. *Developmental Psychology*, *44*, 575–587.

Wiebe, S. A., Sheffield, T., Nelson, J. M., Clark, C. A. C., Chevalier, N., & Espy, K. A. (2011). The structure of executive function in 3-year-olds. *Journal of Experimental Child Psychology*, *108*, 436–452.

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. *Biological Psychiatry*, *57*, 1336–1346.

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). The development of inhibitory control across the life span. *Developmental Psychology*, *35*, 205–213.

Willoughby, M. T., & Blair, C. B. (2011). Test-retest reliability of a new executive function battery for use in early childhood. *Child Neuropsychology*, *17*, 564–579.

Willoughby, M. T., Blair, C. B., Wirth, R. J., & Greenberg, M. (2010). The measurement of executive function at age 3 years: Psychometric properties and criterion validity of a new battery of tasks. *Psychological Assessment*, *22*, 306–317.

Willoughby, M. T., Blair, C. B., Wirth, R. J., & Greenberg, M. (2012). The measurement of executive function at age 5: Psychometric properties and relationship to academic achievement. *Psychological Assessment*, *24*, 226–239.

Willoughby, M. T., Kupersmidt, J. B., & Voegler-Lee, M. E. (2012). Is preschool executive function causally related to academic achievement? *Child Neuropsychology*, *18*, 79–91.

Willoughby, M., Kupersmidt, J., Voegler-Lee, M., & Bryant, D. (2011). Contributions of hot and cool self-regulation to preschool disruptive behavior and academic achievement. *Developmental Neuropsychology*, *36*, 162–180.

Willoughby, M. T., Wirth, R. J., & Blair, C. B. (2012). Executive function in early childhood: Longitudinal measurement invariance and developmental change. *Psychological Assessment*, *24*, 418–431.

Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, H., & Evans J. J. (1996). *The behavioural assessment of the dysexecutive syndrome*. Bury St Edmunds, England: Thames Valley.

Wilson, C. R. E., Gaffan, D., Browning, P. G. F., & Baxter, M. G. (2010). Functional localization within the prefrontal cortex: missing the forest for the trees? *Trends in Neuroscience*, *33*, 533–540.

Wright, A., & Diamond, A. (2014). An effect of inhibitory load in children while keeping working memory load constant. *Frontiers in Psychology*, *5*. doi:10.3389/fpsyg.2014.00213

Yakovlev, P. I., & Lecours, A. R. (1967). The myelogenetic cycles of regional maturation of the brain. In A. Minkowski (Ed.), *Regional development of the brain in early life* (pp. 3–70). Oxford, England: Blackwell.

Yott, J., & Poulin-Dubois, D. (2012). Breaking the rules: Do infants have a true understanding of false belief? *British Journal of Developmental Psychology*, *30*, 156–171.

Zelazo, P. D. (2004). The development of conscious control in childhood. *Trends in Cognitive Sciences*, *8*, 12–17.

Zelazo, P. D. (2006). The Dimensional Change Card Sort (DCCS): A method of assessing executive function in children. *Nature Protocols*, *1*, 297–301.

Zelazo, P. D., Anderson, J. A., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). NIH Toolbox Cognition Battery (CB): Measuring executive function and attention. *Monographs of the Society for Research in Child Development*, *78*, 16–33.

Zelazo, P. D., & Carlson, S. M. (2012). Hot and cool executive function in childhood and adolescence: Development and plasticity. *Child Development Perspectives*, *6*, 54–60.

Zelazo, P. D., Carter, A., Reznick, J. S., & Frye, D. (1997). Early development of executive function: A problem solving framework. *Review of General Psychology*, *1*, 198–226.

Zelazo, P. D., & Frye, D. (1998). II. Cognitive complexity and control: The development of executive function. *Current Directions in Psychological Science*, *7*, 121–126.

Zelazo, P. D., & Jacques, S. (1997). Children's rule use: Representation, reflection, and cognitive control. *Annals of Child Development*, *12*, 119–176.

Zelazo, P. D., & Lyons, K. E. (2012). The potential benefits of mindfulness training in early childhood: a developmental social cognitive neuroscience perspective. *Child Development Perspectives*, *6*, 154–160.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical children. In U. Goswami (Ed.), *The Blackwell-Wiley handbook of childhood cognitive development* (pp. 445–469). Oxford, England: Blackwell.

Zelazo, P. D., & Müller, U. (2010). Executive function in typical and atypical children. In U. Goswami (Ed.), *The Blackwell-Wiley handbook of childhood cognitive development* (2nd rev. ed., pp. 574–603). Oxford, England: Blackwell.

Zelazo, P. D., Müller, U., Frye, D., & Marcovitch, S. (2003). The development of executive function in early childhood. *Monographs of the Society for Research on Child Development*, *68*, vii–137.

Zelazo, P. D., & Reznick, J. S. (1991). Age-related asynchrony of knowledge and action. *Child Development*, *62*, 719–735.