UNITY AND DIVERSITY OF EXECUTIVE FUNCTIONING ACROSS CHILDHOOD AND ADOLESCENCE: LATENT FACTOR STRUCTURE AND ASSOCIATIONS WITH SUBCLINICAL EMOTIONAL AND BEHAVIORAL PROBLEMS

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Abstract

The primary objectives of the present study were to determine empirically the structure and organization of three executive function (EF) factors – Working Memory, Shifting, and Verbal Fluency – and to examine concurrent associations between EF and subclinical internalizing and externalizing behavior problems in a sample of children and adolescents 7 to 18 years of age (*M* = 11.43 years, *SD* = 3.43). Additionally, developmental differences in associations between EF and psychosocial functioning were investigated by comparing latent factor organization across age-based sub-groups.

Data were collected from a large, nationally-representative sample of healthy children and adolescents (*N* = 352), and analyzed at the level of latent constructs rather than observed (i.e., manifest) variables. Results of a series of confirmatory factor analyses (CFA) revealed that a three-factor, fully intercorrelated solution provided the best fit to the available data, thus supporting a conceptualization of working memory, shifting, and verbal fluency as distinct yet related higher-order cognitive processes. Additional CFAs were then conducted to assess the impact of non-executive control variables – crystallized verbal intelligence and processing speed – on the latent factor structure of EF. Although both control factors accounted for significant variance in all EF measures, non-executive skills could not account entirely for performance on EF tasks. Furthermore, the inclusion of control variables differentially impacted latent factor structure, highlighting the utility of partitioning non-executive variance for understanding the organization of EF.

CFAs examining associations between EF factors and psychosocial functioning revealed that individual differences in certain domains of EF track meaningfully and in expected directions with subclinical emotional and behavioral problems. Externalizing difficulties, in particular, were more reliably predicted by Working Memory and Verbal Fluency factors, although these domains of functioning did account for marginally significant portions of variance in Internalizing problems as well. Finally, looking across developmental sub-groups, results failed to reveal a consistent pattern of interrelations between latent EF and emotional/behavioral problems factors. Nonetheless, there was at least some evidence that EF becomes increasingly relevant to psychosocial functioning across childhood/adolescence, particularly with respect to Internalizing difficulties. Findings are discussed in terms of basic and clinical implications, as well as directions for future research.

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CHAPTER 1

Statement of the Problem

Structure and organization of executive function

The term "executive function" generally refers to an array of higher-order cognitive self-regulatory mechanisms employed in the guidance of future-oriented behavior (e.g., Robbins, 1996; Stuss, 1992; Zelazo & Cunningham, 2007; Zelazo, Müller, Frye, & Marcovitch, 2003), and often includes constructs such as working memory, inhibitory control, problem-solving, set-shifting, and verbal fluency. Scientific interest in executive function (EF) began over a century ago when clinicians first started to recognize distinct patterns of cognitive impairment and social dysfunction among adults who had sustained frontal head injuries (Harlow, 1868; Blumer & Benson, 1975; Stuss & Benson, 1984). Since that time, several theoretical and statistical models have been developed to characterize the complex organization and structure of EF (Teuber, 1972; Zelazo, Carlson, & Kesek, 2008). Whereas some have posited a unitary/domain-general understanding based on the notion that seemingly varied executive functions are actually manifestations of – or are facilitated by – the same fundamental mechanism (e.g., Duncan, Johnson, Swales, & Freer, 1997; Kimberg & Farah, 1993; Kimberg, D'Esposito, & Farah, 1997), others have suggested that EF is multi-faceted, comprised of distinct yet related component processes (e.g., Miyake et al., 2000; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003). Determining which of these conceptualizations more accurately captures the complexity of EF has proven a challenging endeavor.

Until recently, researchers have relied heavily on traditional statistical methods such as correlation and exploratory factor analysis (EFA) to test theories of executive function (Miyake, et al., 2000; Zelazo & Müller, 2002). Unfortunately, these techniques have several important drawbacks. The first concerns the use of traditional data reduction methods such as EFA. Most often, EFA has been adopted by investigators presented with the precarious decision of how best to conduct meaningful statistical examination of a data set comprised of multiple putative executive function measures. Rather than risk capitalizing on chance by performing numerous statistical tests, many have preferred to subject their data to exploratory factor analysis, and subsequently to use extracted factors in hypothesis-testing.

Levin et al. (1991), for example, administered a battery of purported EF tasks [e.g., verbal and design fluency, Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), Tower of London (Shallice, 1982), twenty questions, delayed alternation, go/no go] to a normative sample of 52 children ranging in age from 7 to 15 years. To better understand the underlying structure of their data, a total of seven EF test scores were then subjected to principal components factor analysis from which three significant factors were extracted (i.e., "semantic association and concept formation," "freedom from perseveration," and "planning and strategy"). Welsh, Pennington, and Groisser (1991) and, more recently, Brocki and Bohlin (2004) also addressed the question of whether EF constructs tapped into a shared underlying factor or several independent domains. Similar to Levin et al. (1991), these research teams conducted principal components analyses that yielded three-factor solutions. However, whereas Welsh et al. (1991) found evidence for “fluid and speeded response,” “hypothesis testing and impulse control,” and “planning” factors, Brocki and Bohlin (2004) identified “disinhibition,” “speed/arousal,” and “working memory/fluency” factors. One source of these obvious differences was undoubtedly related to the variability in EF test-selection across sites. In addition, subjectivity in factor interpretation has proven to be one of the most persistent difficulties associated with the use of EFA in executive function research. This is especially true when extracted factors are constructed from seemingly unrelated measures and explained *a posteriori*, without sufficient theoretical guidance (Zelazo, Carter, Reznick, & Frye, 1997; Miyake et al., 2000; van der Sluis, de Jong, & van der Leij, 2007).

A second and perhaps more fundamental difficulty associated with executive function research involves assessment and the so-called “task impurity problem” (e.g., Denckla, 1994). Given the inherent complexity of higher-order cognition, the assessment of executive function necessarily entails the administration of multi-factorial tasks that draw from several lower-order executive and non-executive skills (Miyake et al., 2000; van der Sluis et al., 2007). Consequently, there is no such thing as a “pure” measure of EF (Zelazo et al., 1997). Moreover, interpretation of test scores must be informed by consideration of not only what the test purports to measure, but also by an appreciation of the multiple additional factors that could potentially be contributing to a given individual’s performance. While it is true, of course, that psychometric limitations such as these are germane to many areas of psychological research, they are particularly problematic when attempting to conceptualize the underlying organization of EF constructs whose manifest associations may be artificially inflated or diminished by a multitude of factors (e.g., basic sensory/perceptual functioning, information processing speed, fine motor control). Traditional statistical methods such as EFA are unable to account effectively for putative third-party variables, and thus increase the risk that factor clusters will be extracted on the basis of theoretically unrelated features (van der Sluis et al., 2007). Furthermore, significant associations between EF measures may be masked by extraneous factors, thereby lending undue weight to the distinctness of EF constructs (Miyake et al., 2000).

Taken together, these significant limitations suggest that alternative data analytic strategies are warranted for examination of the underlying factor structure of executive function. Latent variable modeling offers such an alternative (see also Senn, Espy, & Kaufmann, 2004 for a discussion of using path analysis in EF research). Although the relevance of latent factors in psychological research has been recognized for some time (e.g., Cronbach & Meehl, 1955; Meehl, 1978), Miyake and his colleagues (2000) were the first to apply a latent variable framework to the investigation of EF (in college-age adults). Lehto et al. (2003), Huizinga, Dolan, and van der Molen (2006), and van der Sluis et al. (2007) followed shortly thereafter with studies examining EF organization and factor structure in childhood and adolescence. These four investigations provide the foundation for the current study, and will, therefore, be discussed in some detail.

In a sample of 137 undergraduate students from the University of Colorado at Boulder, Miyake et al. (2000) administered nine individual performance tasks, each thought to tap into one of three "target" executive functions: 1) Updating (i.e., Working Memory), 2) Shifting, and 3) Inhibition. A systematic series of latent variable confirmatory factor analyses (CFA) was then conducted to determine empirically the best-fitting model from among several hypothesized configurations. Miyake et al. (2000) outlined the logic of this analytic approach as follows:

> If the three target executive functions are distinguishable constructs, then the full three-factor model…should provide a significantly better fit to the data than either model that assumes the unity of all three executive functions (called the "one-factor" model) or the models that assume the unity of two of the executive functions (called the "two-factor" models). If the three executive functions actually are completely unitary and essentially the same construct, then the one-factor model should provide a fit to the data that is statistically no worse than the more complex three-factor or two-factor models. Finally, if the three functions are entirely separate, then the "three independent factors" model, in which all the interfactor correlations are set to zero, should provide a fit to the data similar to that of the model in which the correlations are allowed to vary freely. (p. 69)

Comparison of fit indices revealed that the full three-factor model did, as predicted, provide the best fit to the data. Thus, Miyake and colleagues (2000) concluded that EF is best conceptualized as multi-faceted, consisting of distinguishable yet related latent constructs.

A very similar statistical approach was undertaken by Lehto et al. (2003) in a sample of Finnish children ranging in age from 8 to 13 years (N = 108). Participants were administered a battery of EF tasks chosen as putative indicators of the same latent constructs (i.e., Working Memory, Shifting, and Inhibition). One-, two-, and three-factor models were then examined using CFA. Like Miyake et al. (2000), these authors also found evidence supporting the unity and diversity of executive functions as demonstrated by the superior fit of an interrelated (i.e., non-independent) three-factor model.

However, not all studies have yielded this exact pattern of results. Huizinga and colleagues (2006), for example, looked at the development of EF in three subgroups of normally developing children (ages 7, 11, and 15 years), as well as a group of young adults (age 21-years) living in the Netherlands. Similar to previous studies, these authors postulated the existence of three correlated EF latent factors (Working Memory, Shifting, and Inhibition). They also took an important step beyond previous work by controlling for basic processing speed as a potential confounding factor. Looking first at the sample as a whole (*N* = 384), the results of a confirmatory factor analysis revealed significant Working Memory and Shifting factors; however, contrary to predictions (cf. Salthouse, Atkinson, & Berish, 2003), putative Inhibition tasks [i.e., Stop-signal (e.g., Van Boxtel, Van der Molen, Jennings, & Brunia, 2001), Ericksen Flankers (e.g., Ridderinkhof & Van der Molen, 1995), and Stroop (1935)] failed to load significantly onto a common latent factor. Consequently, each manifest inhibition variable was treated as a separate, single-indicator latent factor.

Huizinga and colleagues (2006) then conducted a series of multi-group, simultaneous CFAs to assess developmental differences in latent factors across the four age groups. Seven- and 11-year olds differed significantly from young adults with respect to four out of five latent factors (Stroop did not differ), as well as basic processing speed. In addition, young adults demonstrated significantly better Working Memory and processing speed than 15-year olds. Therefore, it was concluded that whereas adult-level performance in Shifting and some aspects of Inhibition is reached by adolescence, trajectories of latent Working Memory and processing speed factors continue to evidence significant refinement well into young adulthood. More broadly, these results supported an understanding of EF as non-unitary and multi-faceted.

Finally, in a separate study of 172 children (M_{age} = 10.5 years) in the Netherlands, van der Sluis and colleagues (2007) were also unable to extract a latent Inhibition factor while controlling for non-executive (e.g., processing speed) variance. Interestingly, although both Updating (i.e., working memory) and Shifting latent factors were identified, their shared intercorrelation dropped below conventional significance levels once control variance was considered. This finding raised the possibility that studies failing to control for non-executive variance (e.g., Miyake et al., 2000; Lehto et al., 2003) may have overestimated associations among latent EF factors.

In sum, latent variable statistical modeling has proven a useful tool for executive function research. To date, Updating/Working Memory, Shifting, and Inhibition have been the most-examined latent EF factors in both adult (e.g., Miyake et al., 2000) and child/adolescent samples (Lehto et al., 2003; Huizinga et al., 2006; van der Sluis et al., 2007; see also Garon, Bryson, & Smith, 2008 for review); however, results have differed across studies, particularly with respect to the identification of a latent Inhibition factor. Studies have also varied in their inclusion of putative control variables such as information processing speed, despite nearly universal agreement that task impurity poses one of the most significant challenges to research in this domain. Furthermore, despite mounting evidence of socioeconomic influences on EF skills (e.g., Noble, Norman, & Farah, 2005), most studies have tended to utilize community-based convenience samples without describing the implications of their representativeness to larger populations of interest. Thus, the generalizability of existing research remains largely unknown.

The current study was designed as both a partial replication and extension of previous research investigating the underlying structure and organization of executive function. In addition, several important limitations of prior studies were addressed. First, data were collected from a large, nationally-representative sample of normally developing children and adolescents, stratified by gender, race, and socioeconomic status, according to the 2000 United States Census. Second, theoretically-derived control variables (i.e., processing speed and crystallized verbal intelligence) were included, and latent variable models were tested with and without these variables to determine their relative impact on latent factor structure. Third, unlike previous studies, a latent Verbal Fluency factor was included in the current investigation. Finally, developmental differences in latent EF factor structure were examined by comparing CFA models across four age-based subgroups: 1) early elementary school, 2) elementary school, 3) junior high school/early adolescence, and 4) high school/adolescence.

EF and associations with childhood and adolescent psychosocial functioning

Considerable research suggests that individual variation in executive function tracks meaningfully with aspects of psychosocial functioning at both clinical and subclinical levels. Indeed, children and adolescents with more well-developed executive functions are, on average, more socially competent (e.g., Razza & Blair, 2009; Riggs, Jahromi, Razza, Dillworth-Bart, & Mueller, 2006; Calkins & Marcovitch, 2010; Ciairano, Visu-Petra, & Settanni, 2007; Clark, Prior, & Kinsella, 2002), exhibit fewer emotional and behavioral problems (e.g., Cole, Usher, & Cargo, 1993; Emerson, Mollet, & Harrison, 2005; Riggs, Blair, & Greenberg, 2003; Romer et al., 2009), and perform better in school (e.g., Morrison, Ponitz, & McClelland, 2010) than their lower-EF counterparts.

Of course, assessment of hypothesized associations between EF and social/emotional functioning is also limited by task impurity and inadequate traditional statistical methods, as discussed in the previous section. Surprisingly, despite growing recognition of the utility of latent variable modeling for understanding the organization of EFs, as well as explaining variance in more complex EF tasks (e.g., WCST, Tower of London, Tower of Hanoi; Huizinga et al., 2006; Miyake et al., 2000) and diverse cognitive abilities such as reading and arithmetic (van der Sluis et al., 2007), to date, there have been no latent variable investigations of EF and psychosocial functioning. To address this important limitation, the current study examined latent associations between EF and sub-clinical externalizing and internalizing problem factors extracted from well-validated parent-report measures (i.e., Child Behavior Checklist; Achenbach, 2001).

An additional limitation of previous studies has been the tendency to overlook possible developmental implications of associations between EF and psychosocial functioning. Societal expectations regarding independent self-regulation increase over the course of childhood and adolescence (e.g., Thompson, 1994; Thompson & Meyer, 2007). An adolescent's temper tantrum, for example, would generally be regarded as more aberrant than a preschooler's because by the time an individual reaches adolescence, he or she is *expected* to have acquired more effective means of managing frustration. Thus, an individual's ability to regulate heightened emotions is influenced not only by the current state of his or her executive control skills, but also by more macro-level systemic factors dictating what is appropriate social behavior at a given point in development. By extension, it is feasible that difficulties with self-regulation may become stronger predictors of psychosocial maladaptation with age, as the salience of socially inappropriate behaviors increases. This hypothesis was examined in the current study by comparing relative associations between EF and emotional/behavioral problems across developmental sub-groups.

CHAPTER 2

Review of Relevant Literature

History of executive functioning research

Scientific interest in executive functioning began over a century ago, sparked by increased interest in the cognitive and behavioral profiles of patients with various frontal lobe injuries. The earliest published account appeared in 1835 and detailed the profound personality changes experienced by an adolescent who sustained a self-inflicted gunshot wound (Blumer & Benson, 1975, as cited in Stuss & Benson, 1984). Still, the most well-known case example remains Phineas Gage. As a twenty-five year old railroad construction foreman in 1848, Gage survived a terrible accident in which an explosion caused an iron tamping rod to be shot upward, through his left cheek, and out through the top of his head (Harlow, 1868; Damasio, 1994; Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994). Interestingly, although Gage's general intellectual capacities remained intact after his injury, profound personality and behavior changes made him nearly unrecognizable to those who knew him (Damasio et al., 1994). This incident drew attention to the neuroanatomical basis of complex personality traits, and provided some of the earliest documented evidence for the role of the brain in regulating social behavior (Luciana, 2006).

Fueled by the prior achievements of Paul Broca (e.g., 1865) and Carl Wernicke (e.g., 1874) in identifying the neural infrastructure of language, the start of the 20th century ushered in an era of enduring fascination with solving the so-called "riddle of frontal lobe function in man" (Teuber, 1964). Although investigations of brain-injured individuals continued to provide important clues, studies of neurologic conditions implicating frontal areas (e.g., frontal lobe tumor, Huntington's disease) and frontal psychosurgery (i.e., prefrontal leucotomy/lobotomy) patients also shed some important light on this question (see Stuss & Benson, 1984; Jasper, 1995). Not surprisingly, these studies were plagued by serious methodological limitations. Prefrontal lobotomy patients, for example, were for obvious reasons not randomly selected, often seeking surgical remediation of chronic, severe, and otherwise intractable emotional dysfunction (Jasper, 1995). Despite an estimated 100,000 such procedures in the 1940s and 1950s alone, presurgical evaluations were rare and postsurgical evaluations were confounded by atypical premorbid functioning and/or a focus on psychiatric symptom resolution as their primary outcome measure (Stuss & Benson, 1984).

Still, one of the greatest challenges faced by clinical researchers at that time was the lack of a consistent "frontal lobe syndrome" in their patients. Whereas some appeared much like Phineas Gage (i.e., behaviorally disinhibited, socially inappropriate, childish), others presented depressed, withdrawn, anhedonic, apathetic, and at times even mute (Stuss & Benson, 1986; Pennington & Ozonoff, 1996). Stuss and Benson (1986) referred to the former variant as *pseudopsychopathic* and the latter as *pseudodepressed* in an effort to differentiate behavioral phenotypes and distinguish more traditional psychiatric syndromes from those brought on by organic neurologic insult. Although these and other investigators would later attempt to ascribe different syndromes to dysfunction within distinct regions of the prefrontal cortex (e.g., medial vs. orbital lesions; Stuss & Benson, 1986), for early researchers, this apparent behavioral multifinality (i.e., multiple outcomes from a single starting point; Cicchetti & Rogosch, 1996) imposed a significant limitation on the predictive power of their explanatory models and made the "riddle of frontal lobe function" all the more puzzling.

With respect to the frontal lobe and cognition, Brenda Milner contributed some of the earliest evidence of the specific kinds of deficits associated with relatively selective prefrontal cortex (PFC) damage. According to Milner (1995), pre- and postsurgical neurocognitive testing of epilepsy surgery patients became commonplace around the mid-20th century at the Montreal Neurological Institute. Using a battery of tests comprised both of well-recognized measures of intellectual functioning and relatively newer tasks such as the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948) – which, incidentally, is now considered by some to be "the prototypical EF task in neuropsychology" (Pennington & Ozonoff, 1996, p. 55) – it was possible for Milner (1963; 1995) to demonstrate a dissociation between intelligence and executive function in individuals with PFC lesions. The WCST is a test of cognitive flexibility, problem-solving, and inductive reasoning in which test-takers are asked to sort cards according to three parameters (color, form/shape, and number); however, they are not actually told what rule they are to use while sorting. As the test progresses and a critical number of correct sorts is reached, the sorting rule changes thereby requiring the patient to discover the new strategy. Despite initial success in finding a correct sorting strategy, Milner (1963) showed that individuals with frontal-lobe lesions often failed to adapt when a new rule was enacted. Rather, they persisted in sorting based on the same incorrect strategy (i.e., perseveration), even in the face of recurring negative feedback.

In sum, early executive function research was born out of clinical case reports and small studies documenting unique patterns of behavioral and cognitive impairment in patients with various frontal lobe injuries. Although fraught with methodological limitations, these studies were some of the first to define the neural underpinnings of higher-order brain functions and demonstrate the role of the prefrontal cortex in regulating complex and distinctly human social behavior.

Theories of executive function

As clinicians and scientists became increasingly interested in the study of higher-order cognition, the need for an organizing framework prompted the development of several theories of executive function. Some of the more prominent theories have discussed the relative primacy of specific executive skills such as working memory, inhibitory control, and problem-solving within the broader structure of EF.

One of the most influential accounts to date has been Baddeley and Hitch's (1974; Baddeley, 1986) three-factor model of working memory (i.e., an active process involved in the online representation and mental manipulation of information to guide future behavior; e.g., Goldman-Rakic, 1987). Although not strictly a "model of executive function," per se, these authors posited the existence of a "central executive" that operated as a supraordinate cognitive structure responsible for regulating subordinate phonological (i.e., auditory/verbal) and visuospatial working memory systems[1]. Through coordination of lower-order processes, the central executive was thought to facilitate goal-directed behavior by allowing the active, simultaneous manipulation of multiple pieces of information.

[1] Baddeley (2000) subsequently added a third subordinate system, the episodic buffer, to this model.

More recent theorists, by extension, have implicated reduced working memory (WM) capacity as the primary factor limiting the executive capabilities of children (e.g., Case, 1992) – a hypothesis based, in part, on mounting evidence of the prolonged developmental course of WM (e.g., Luciana & Nelson, 1998; Luciana, Conklin, Hooper, & Yarger, 2005; Conklin, Luciana, Hooper, & Yarger, 2007). Aspects of spatial working memory such as strategic self-organization, for example, reach adult-levels at approximately 16 to 17 years of age (Luciana et al., 2005), while verbal working memory skills continue to gain sophistication throughout adolescence and young-adulthood in accordance with known patterns of frontal lobe refinement and integration (Conklin et al., 2007), particularly within dorsolateral regions of the prefrontal cortex (D'Esposito et al., 1995; Diamond & Goldman-Rakic, 1989; Braver et al., 1997).

Other EF theorists have discussed the relative primacy of inhibitory control among the constellation of executive functions. Luria, Pribram, and Homskaya (1964), for instance, observed that "…the patient with frontal lobe destruction…is unable to inhibit impulsive reactions or to hold back the tendency towards fixed repetition of movement" (as cited in Canavan, Janota, & Schurr, 1985, p. 1049). In essence, accounts such as these assert that the capacity to withhold undesired behaviors grants one the opportunity to avoid impulsivity and enact subordinate regulatory mechanisms. Barkley's (1997) model of Attention-Deficit/Hyperactivity Disorder (ADHD) offers a clear illustration (see also Nigg, 2000). Briefly, Barkley (1997) suggested that effective behavioral inhibition and impulse control permit the recruitment of lower-order executive processes such as affect regulation, self-speech, and working memory, which could then be utilized in modulating attention and activity level. Thus, according to this model, even adult-level lower-order EFs would be inaccessible in the absence of a supraordinate inhibitory control mechanism by which potentially maladaptive response tendencies are restrained.

More recently, Zelazo and his colleagues (e.g., 1997; 2003) offered a problem-solving framework for conceptualizing executive function. According to these authors, previous theories characterized EFs in essentially "homuncular" terms that did little to explain "*how* [italics added] executive function is accomplished" (Zelazo et al., 2003, p. 1). Toward this end, they outlined a series of four distinct steps through which the successful navigation of executive task performance progresses. These steps include: 1) problem representation, 2) planning, 3) execution (intending/rule-use), and 4) evaluation (error detection/correction). Thus, a child (or adult) who is unable to pass an executive function task such as the Wisconsin Card Sorting Test, for example, may have failed to attend to and/or accurately understand the nature of the problem at hand; to generate feasible strategies for responding; to override prepotent response tendencies in order to execute alternate strategies; and/or to alter ineffective strategy-use based on examiner feedback.

Of note, Zelazo et al.'s (1997) problem-solving framework, although initially advanced for the purposes of better understanding the development of cognitive self-regulation, has also been applied to questions of psychosocial adaptation and developmental psychopathology (e.g., Séguin & Zelazo, 2005). Consider, for example, a child who overhears that a classmate is throwing a party to which she has not received an invitation. The perception of her apparent exclusion from this social event may prompt in her an uncomfortable emotional response (e.g., anger, sadness, frustration). If sufficiently heightened and dysregulating, this uncomfortable emotion state can rightfully be considered a problem for the child because she is forced to manage her emotional condition while also having to pay attention to her teachers, perform in class, navigate interactions with peers, etc. Executive function may play a role in the unfolding of this situation at several stages including:

1) the child's interpretation of the problem situation (e.g., "I was not invited; the other children don't like me" vs. "My invitation is coming");
2) identification of her specific goal(s) (e.g., "I want to hurt the child who is hurting me"), as well as her understanding of the possible consequences associated with her various response options (e.g., "If I hit the offending child, I will get in trouble;" "If I spread a nasty rumor about the offending child, I will feel better");
3) enactment of a strategy or strategies for attaining her goal; and,
4) evaluation/adjustment of strategies based on feedback.

Thus, social problem-solving may be understood using an EF framework. Still, the previous example fails to adequately address the emotional context within which social problems so often transpire. The role of emotion in models of EF will now be discussed in terms of "hot" versus "cool" executive functions.

Hot and cool executive function

Another important distinction with respect to the organization of EF involves the relative salience of emotion in cognitive and behavioral self-regulation (e.g., Zelazo & Müller, 2002; Zelazo & Cunningham, 2007). Despite growing recognition of the distinction between affective or “hot” EF (which involves the ventral-medial/orbitofrontal regions of the prefrontal cortex, as well as densely interconnected limbic regions) and “cool” EF (which primarily involves the dorsolateral prefrontal cortex), as well as neuroimaging evidence of the differential timing of structural maturation across PFC regions (Giedd et al., 1999), traditional executive functioning tasks tap almost exclusively into decontextualized, “cool” cognitive processes (e.g., Zelazo & Müller, 2002; Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

Theoretically, as the motivational significance of a task increases, so does the need to regulate co-occurring emotional processes in order to successfully complete the task (Zelazo & Cunningham, 2007). Accordingly, “hot” and “cool” executive functions are perhaps better conceptualized as points along a continuum rather than categorically distinct (Hongwanishkul et al., 2005; Manes et al., 2002; Zelazo & Cunningham, 2007). The Wisconsin Card Sorting Test (Grant & Berg, 1948) and Dimensional Change Card Sort (Zelazo, 2006), for example, involve the relatively emotionally neutral sorting of stimulus cards based on parameters such as color, shape, and quantity. Inhibitory control tasks such as the classic Go/No-Go are also relatively emotionally decontextualized (i.e., “cool”), although emotional reactions are not entirely unheard of during both card sorting tasks and Go/No-Go tasks, especially if an individual realizes that he or she is performing poorly.

On the other hand, the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994), as well as the more recent Children's Gambling Task (Kerr & Zelazo, 2004), recruit both ventral-medial/orbitofrontal and dorsolateral prefrontal cortical systems by requiring individuals to make decisions that yield motivationally salient rewards and losses (e.g., money, candy). Similarly, well-known developmental constructs such as "theory of mind" (e.g., Wellman, 1990; Zelazo & Müller, 2002) and "delay of gratification" (e.g., Mischel, Shoda, & Rodriguez, 1989) are also thought to be more affectively-charged, thus demanding the recruitment of both "hot" and "cool" executive functions (Séguin & Zelazo, 2005). These tasks may provide an informative window into the role of EF in socioemotional adaptation, especially if integrated with more traditional "cool" EF measures (Séguin & Zelazo, 2005).

Indeed, the question of how executive function interfaces with emotion regulation is likely integral to understanding the role of EF in psychosocial functioning. Zelazo and Cunningham (2007) posited that "a successful approach to solving hot problems is to reconceptualize the problem in relatively decontextualized terms and try to solve it using cool EF…reflecting on the situation, creating more complex rule systems, and recruiting more lateral regions of the PFC" (p. 145). According to this model, a child who is able to down-regulate emotionally-laden problems and relegate them to "cooler" domains should be more effective in navigating real-world, affectively-charged interpersonal conflicts (Séguin & Zelazo, 2005). Theoretically, the emergence of the capacity to perform such an operation likely follows a protracted course. Considering that dorsolateral regions of the PFC are the last to reach adult-levels (Giedd et al., 1999; Luciana, 2006) – thus making them particularly vulnerable to disruption via environmental influences (e.g., injury, stress; Casey, Giedd, & Thomas, 2000) – individual variation in the hierarchical integration of cortico-cortical and cortical-subcortical networks may be directly related to one's ability to engage in "cool" social problem-solving.

Interestingly, this model also seems to imply that traditional assessment of "cool" EF may be sufficient for understanding links between EF and social behavior. However, as several studies and clinical case reports have documented, orbitofrontal cortex (OFC) damage is often associated with severe social dysfunction and deficits in "hot" EF (i.e., Iowa Gambling Task performance; Bechara et al., 1994) within the context of otherwise preserved cognition (e.g., Damasio, 1994). This apparent contradiction highlights what is perhaps the most fundamental limitation of viewing the brain as modular (e.g., Fodor, 1983) rather than as an interconnected network of specialized regions. The risk in adopting a modular framework is in interpreting even focal disruption as causally related to associated cognitive and social deficits without giving adequate consideration to other up- and/or downstream effects on linked neural systems. For example, Manes et al. (2002) showed that even the IGT recruits "cool" regions of the PFC, particularly the dorsolateral PFC, in addition to OFC regions. Thus, poor performance on the IGT may be attributable to several causes. Similarly, interpersonal interaction failures are likely attributable to disruption at various points along the hierarchical organization of the PFC. Therefore, understanding the interplay of "hot" and "cool" executive functions will likely prove crucial to the development of more useful theories of EF involvement in psychosocial functioning.

EF and psychosocial functioning during childhood and adolescence

Given the conceptualization of executive functions as fundamental components of cognitive and behavioral self-regulation, it is perhaps not surprising that EF skills correlate with multiple aspects of emotional and behavioral functioning (Pennington & Ozonoff, 1996; Zelazo et al., 2008). This section will provide a review of relevant literature addressing the role of EF in externalizing (e.g., aggression, rule-breaking) and internalizing (e.g., depression, anxiety) problems.

Externalizing problems

In the opening paragraph of her now classic paper on the neuropsychology of conduct disorder, Moffitt (1993b) cited Benjamin Rice (1812) as saying that those individuals who exhibit so-called "innate preternatural moral depravity" probably have "an original defective organization in those parts of the body which are occupied by the moral faculties of the mind" (cited in Elliott, 1978, p. 147). Due in large part to the investigations of Moffitt and her colleagues, executive dysfunction is now widely recognized as a risk factor for externalizing behavior problems in children and adolescents. Indeed, there exists a large literature on the executive deficits associated with antisocial syndromes such as conduct disorder and juvenile delinquency (see Lynam & Henry, 2001; Moffitt, 1993b; Morgan & Lilienfeld, 2000; Séguin, Arseneault, & Trembley, 2007; Séguin, Sylvers, & Lilienfeld, 2007; Teichner & Golden, 2000 for reviews). Controlling for variables such as socioeconomic status, race, and test motivation, juvenile delinquents tend to exhibit diminished executive functioning skills, as well as lower overall intelligence and poorer verbal reasoning abilities than nondelinquent controls (Lynam, Moffitt, & Stouthamer-Loeber, 1993; Moffitt, 1993b). In addition, a more recent meta-analysis comprised of thirty-nine studies and 4,589 participants (age range: approximately 12-34 years) demonstrated that antisocial individuals perform, on average, .62 standard deviations worse on standardized EF measures than contrast group members (Morgan & Lilienfeld, 2000).

Looking more specifically at aggressive forms of childhood and adolescent externalizing problems, mounting evidence implicates executive dysfunction as a risk factor for both concurrent and future maladaptation. Jean Séguin and his colleagues' (Séguin, Pihl, Harden, Tremblay, & Boulerice, 1995; Séguin, Boulerice, Harden, Trembley, & Pihl, 1999; Séguin, Nagin, Assaad, & Tremblay, 2004) have contributed greatly in this respect. Séguin et al. (1995) used teacher reports to assess stability of physical aggression in a community sample (N = 177) of white, French-speaking boys at ages 6, 10, 11, and 12 years. These children were drawn from a larger sample of 1037 low SES boys who have been followed by this research team since the children were in kindergarten. Boys were classified as stable aggressive, nonaggressive, or unstable aggressive depending on their respective aggressive behavior histories. Batteries of neuropsychological tests were then administered at 13 and 14 years, the results of which were factor analyzed, ultimately yielding four factors: 1) verbal learning, 2) incidental spatial learning, 3) tactile-lateral ability, and 4) executive functions (which, in this study, largely reflected various working memory skills). Working memory was of particular theoretical interest given its hypothesized role in social information processing and problem-solving (Séguin, 2004). Controlling for familial adversity (i.e., socioeconomic status), as well as other neuropsychological factors (i.e., Incidental Spatial Learning, Tactile Laterality, Verbal Learning), stable aggressive boys were found to exhibit significantly poorer executive functions (working memory) than both nonaggressive and unstable aggressive boys. No other significant main effects were found.

As the first large-scale investigation of its kind, this study contributed importantly to the literature. Most notably, it demonstrated that executive functioning deficits tend to characterize boys with early-onset, persistent aggressive behavior problems – an interpretation generally consistent with Moffitt's (1993a; 2007) taxonomy of life-course persistent antisocial behavior. However, in failing to control statistically for the presence of ADHD, a disorder with known executive dysfunction (Barkley, 1997), findings remained equivocal (Pennington & Ozonoff, 1996). Another prominent limitation was the use of a composite executive function factor comprised of tasks believed to rely on disparate regions of the prefrontal cortex (PFC; Pennington & Ozonoff, 1996). As previously discussed, the prefrontal cortex is made up of several distinct subregions characterized by theoretically dissociable functions and identified by their relative topographical positions (e.g., dorsolateral, ventromedial; Luciana, 2006). In light of Giancola's (1995) review suggesting posterior dorsolateral (but not mid-dorsolateral) PFC involvement in experimentally-induced aggression among adults (e.g., Giancola & Zeichner, 1994), Séguin et al.'s (1995) use of a unitary EF factor was considered a shortcoming because it precluded testing for potentially meaningful differences in neural integrity across subregions (Pennington & Ozonoff, 1996).

To address these limitations, Séguin and colleagues (1999) designed a follow-up study in which 149 white males (of the 177 who participated in Séguin et al., 1995) underwent additional neuropsychological and psychiatric evaluations at 15-16 years of age. Again, adolescents were grouped based on stability of physical aggression (i.e., stable aggressive, nonaggressive, unstable aggressive); however, during this investigation, controls were added for ADHD, as well as for IQ, general memory, and negative emotionality. Two executive function composites: 1) Subjective Ordering and 2) Conditional Association were created to test working memory-related cognitive functions believed to be subserved by mid-dorsolateral PFC and posterior-dorsolateral PFC, respectively (Petrides, Alivasatos, Evans, & Meyer, 1993).

Briefly, Subjective Ordering (SO; e.g., self-ordered pointing) tasks involve the participant looking serially at 12 pages of 3 x 4 picture matrices (i.e., a total of 12 unique pictures arranged in a 3 x 4 array); each page contains the same 3 x 4 picture matrix. Instructions are to point to a different picture on each page without repeating previous selections or utilizing a discernible pattern (e.g., left-to-right, top-to-bottom). Conditional Association (CA) tasks, on the other hand, involve demonstrating newly learned associations between several pairs of stimuli. For example, a participant may be shown six lights and six identical pieces of paper and told that each light corresponds to a particular piece of paper. He or she is then instructed to learn specific light–paper associations by trial-and-error using examiner feedback. Thus, successful completion of

CA tasks requires, in part, the ability to form, maintain, and effectively utilize new rules of association—a skill set theoretically useful in learning to avoid aggressive altercations by associating them with dangerous or otherwise unpleasant reprisals.

Broadly speaking, Séguin et al. (1999) showed that executive functioning deficits were positively related to physical aggression after controlling for ADHD, IQ, memory, and negative emotionality. More specifically, whereas results revealed deficits in Subjective Ordering abilities (mid-dorsolateral PFC) in the stable aggressive boys compared to their nonaggressive peers, it was the unstable aggressive boys who exhibited the hypothesized Conditional Association learning impairments (posterior DL-PFC) relative to both stable aggressive and nonaggressive groups.

Giancola and Zeichner (1994) also found an inverse relation between performance on Conditional Association tasks and aggression in a small community sample of young adult males (*N* = 72) between 18 and 32 years of age (*M* = 21.6 years). These researchers experimentally-induced aggression by having participants compete against a fictitious opponent on a reaction time task in which the "winner" was able to deliver an electric shock of self-determined intensity and duration to the "loser" (i.e., Taylor [1967] reaction-time aggression paradigm). The effects of physical provocation were operationalized as the intensity and duration of shock administered following receipt of a high-intensity shock. Séguin et al. (1999) interpreted their findings in light of Giancola and Zeichner's (1994), suggesting that unstable aggressive adolescent males "may…have a history of aggression because they are more likely to be easily provoked" (p. 1205) and, thus, may be especially prone to reactive physical aggression. Unstable aggressive boys within this same sample have also been found to demonstrate heightened neurotic response perseveration (Séguin, Arseneault, Boulerice, Harden, & Tremblay, 2002) and increased pain sensitivity (Séguin, Pihl, Boulerice, Tremblay, & Harden, 1996) which may make them particularly likely to misperceive even slight physical provocations as threatening (i.e., hostile attribution bias).

This line of research has proven informative in several respects. First, it demonstrated that physical aggression is associated with executive functioning difficulties over and above any shared effects of ADHD symptoms such as inattention, hyperactivity, and impulsivity. Indeed, a subsequent study by Séguin and colleagues (2004) found that chronic physical aggression and hyperactivity bore significant, independent, additive (i.e., not interactive) relations to neuropsychological functioning, specifically working memory, with physical aggression accounting for more variance in test performance than hyperactivity (2-8% vs. 0.1-3%, respectively). This is in contrast to Pennington and Ozonoff's (1996) conclusion that relations between executive dysfunction and conduct disorder (without ADHD) are inconsistent at best. Of course, it should be noted that Pennington and Ozonoff (1996) reviewed studies of conduct disorder and not physical aggression specifically; therefore, lack of significant relations to executive functioning may have been due, at least in part, to the heterogeneity of the CD diagnosis.

Second, although the Séguin et al. (1999) study did not specifically assess for functional subtypes of aggression, the authors' attempt to reconcile their results with both the reactive/proactive aggression and social information processing literatures was an important step forward (cf. Crick & Dodge, 1996). Finally, this work highlighted the usefulness of longitudinal studies capable of documenting stability/instability of aggressive behaviors over time. Patterns of onset, maintenance, and desistance of aggression are subject to recall bias when assessed retrospectively and thus call for prospective designs such as the one used by Séguin et al. (1995, 1999). Nonetheless, this study was not without limitations, most notably its exclusion of female participants and assessments of relational forms of aggression (e.g., Crick & Grotpeter, 1995). Moreover, replication studies using different samples are needed to test the reliability of these findings.

Turning now to research within clinical populations, Giancola, Martin , Tarter, Pelham, and Moss (1996) investigated physical aggression and EF in a large, high-risk sample of 10-12 year old boys (N = 291) whose fathers had lifetime diagnoses of a psychoactive substance disorder (not limited to alcohol or nicotine dependence; n = 190) and controls (n = 101). Aggression was assessed using teacher- and mother-reports, as well as via performance on a modified version of the Taylor (1967) reaction-time aggression paradigm in which children were told they were competing against an opponent (fictitious) from whom they could deduct points for trials "won" and to whom they would lose points on trials "lost." Similar to the original Taylor paradigm, the goal of each trial was to hit a button as quickly as possible following a cue (i.e., a green light). Provocation was manipulated such that half the trials "lost" resulted in a small number of points being deducted ("low provocation") while the other half resulted in a large number of points being deducted ("high provocation"). Executive functions were assessed using five laboratory tasks (Porteus Maze, Vigilance, Forbidden Toy, Motor Restraint, and Block Design) which, when subjected to factor analysis, were found to load on a single EF factor.

Controlling for Verbal IQ, socioeconomic status, and family history of substance dependence, hierarchical multiple regressions demonstrated significant inverse associations between executive functioning and both mother- and teacher-reported aggression. Results from the aggression paradigm also revealed that poorer executive functioning skills predicted increased aggressive responses, but only under “high provocation” conditions. This latter finding may suggest that when provoked, children with more well-developed cognitive self-regulatory capacities are able to recruit those resources to inhibit a retaliatory aggressive response (Giancola, Martin et al., 1996). Of course, such an interpretation is contingent on whether or not this paradigm actually elicits aggression as it purports, and if so, what kind. Since the removal of points is in no way linked to damaging an interpersonal relationship, the responses elicited are clearly not relationally aggressive. However, in considering the functional nature of the responses, it is decidedly less apparent whether the “provoked” removal of another’s points is proactive or reactive. Also, since this paradigm was presented as a game, it is possible that reactions were more of a playful, “rough-and-tumble” nature, rather than attempts to actually hurt or harm the opponent. In conjunction with the lack of significant intercorrelation with mother-reported aggression and only a small (albeit significant) correlation with teacher-reported aggression ($r = 0.17$, $p < .05$), these reservations seem to suggest that additional research testing the validity of the modified (child-version) Taylor paradigm is needed.

Nonetheless, the significant concurrent relations between laboratory-assessed executive functioning and teacher- and mother-reported aggressive behavior suggest that deficits in executive functioning may be associated with increased risk for physical aggression. Moreover, findings from a 2-year prospective investigation of these boys (*N* = 198; Giancola, Moss, Martin, Kirisci, & Tarter, 1996) revealed that executive functioning predicted self-reported reactive physical aggression for children with family histories of substance use/abuse, further strengthening the purported association between EF and impulsive/retaliatory aggression, at least among males. Female participants were not included in the studies reviewed thus far.

Indeed, exclusion of females is a longstanding limitation of much aggression research (Crick & Zahn-Waxler, 2003; Hinshaw, 2002; Zahn-Waxler, 1993). Often the argument to exclude females is based on the robust finding that their base rates of serious physical aggression are significantly lower than those of males (e.g., Keenan & Shaw, 1997). Although this fact is not disputed, it nonetheless fails in several respects to provide an adequate rationale for limiting studies to males. Most notably, it suggests that female aggressive behavior problems are fundamentally identical to those in males, and can thus be adequately conceptualized using single-gender samples. It also overlooks the fact that girls who are identified as physically aggressive may actually fare worse than boys in terms of their psychosocial adjustment (Crick, 1997). Finally, studies only consisting of males make it impossible to identify potentially informative behavioral and/or cognitive self-regulatory factors (e.g., executive function) contributing to the gender imbalance. Therefore, in lieu of empirical evidence confirming that male and female aggressive behavior problems are, in fact, identical—which, of course, would necessitate mixed-gender investigations—researchers should seek to understand aggression in both genders.

Toward this goal, Giancola, Mezzich, and Tarter (1998a, 1998b) conducted two studies of EF and aggressive behavior in adolescent females between the ages of 14 and 18 years. Their first investigation (1998a) looked at disruptive, delinquent, and physically aggressive behavior problems in females with a psychoactive substance use disorder (n = 188), as well as healthy controls (n = 95). Seven putative EF tasks (i.e., Go/No-Go, Stroop, Porteus Maze, Motor Restraint, Object Assembly, Block Design, and Picture Arrangement) were administered, reduced via exploratory factor analysis, and found to load onto a single EF factor. Current and lifetime symptoms of disruptive behavior, delinquency (excluding physically aggressive behaviors), and physical aggression were assessed using a standardized self-report interview (i.e., K-SADS-E). Age and SES (but not IQ) served as covariates in all analyses. Although executive functioning was found to be significantly inversely related to all measured behavior problems, only in the prediction of lifetime physical aggression was EF found to be a stronger predictor than drug use. In contrast, drug use was more strongly associated with current and lifetime symptoms of disruptive behavior and delinquency.

In their second study, Giancola et al. (1998b) examined EF and temperament in a large sample of conduct-disordered females (n = 159) and normal controls (n = 90). Conduct disorder symptoms were separated into physically aggressive and non-aggressive antisocial behavior categories. Executive function tasks were identical to those in Giancola et al. (1998a), and WISC-R/WAIS-R Vocabulary and ADHD status were included as covariates in all analyses. Results showed significant main effects of self-reported temperamental difficulties on both aggressive and non-aggressive antisocial behaviors. However, subsequent analyses revealed that executive functioning partially mediated this effect for physically aggressive antisocial behavior; non-aggressive antisocial behavior continued to be more strongly predicted by temperament.

In addition to being two of the first studies of their kind to be conducted with samples of females, these investigations are notable for at least two other important reasons. First, heterogeneous antisocial behaviors were disaggregated to permit testing of differential associations with independent variables of interest. Both studies found stronger relations between executive functioning and physical aggression than between EF and non-aggressive antisocial behavior, delinquency, or general disruptiveness. Similarly, Barker et al. (2007) demonstrated that while EF deficits increased risk for violence, they actually tended to decrease risk for theft. It seems, therefore, that unitary diagnostic classifications that fail to disentangle aggressive and non-aggressive symptoms may mask important within-group variation. Second, by including factors such as drug use and temperamental features in their analyses, and testing for potential moderator and mediator effects, these studies improved (somewhat) upon earlier direct effects models which are likely too simplistic to account for the various ways executive functions may influence the expression or inhibition of aggressive behavior.

Nonetheless, by virtue of using a single-gender design, the opportunity to examine gender differences was precluded in the Giancola et al. (1998a, 1998b) studies. In fact, only one investigation (i.e., Dery, Toupin, Pauze, Mercier, & Fortin, 1999) has looked specifically at aggression and executive functioning in a mixed-gender sample of adolescents; however, gender differences were not tested. In addition, this study failed to find significant differences in EF across aggressive and non-aggressive conduct disordered adolescents (M_{age} = 15.4 years). Three other mixed-gender studies of aggression and EF in young adults were also identified; two looked at samples of college students (M_{age} = 19 years and 23.01 years in Villemarette-Pittman, Stanford, & Greve, 2002 and Stanford, Greve, & Gerstle, 1997, respectively) and a third looked at a mixed group of healthy young adults 18-30 years of age (*M* = 22 years) recruited from the community and an affiliated college (Hoaken, Shaughnessy, & Pihl, 2003). Relative to controls, self-reported impulsive-aggressive college students committed more impulsive errors on the Wisconsin Card Sorting Test and Trail Making Test (Trails B), exhibited poorer fluent verbal reasoning abilities on the Controlled Oral Word Association Test (Stanford et al., 1997), and demonstrated poorer ability to organize and plan complex verbal output on two story-telling tasks (Villemarette-Pittman et al., 2002). Similarly, Hoaken et al. (2003) found trend level ($p < .10$) relations between behavioral impulsivity on the Go/No-Go task and experimentally-induced aggression (Taylor Aggression Paradigm, 1967), specifically for individuals with less well-developed executive functioning skills. With the exception of males exhibiting more aggression than females, no other significant gender differences were revealed.

More recently, Raaijmakers et al. (2008) examined associations between inhibitory control and physical aggression in a mixed-gender sample of Dutch preschool children. Using parent-reported CBCL aggressive behavior scores at or above the 93rd percentile as a cut-off point, and controlling for attention problems, children high in aggression demonstrated significantly less well-developed inhibition than non-aggressive controls.

Taken together, the results of these four studies suggest that difficulties inhibiting prepotent response tendencies (i.e., impulsivity) and/or engaging in effective language-based verbal reasoning may heighten vulnerability for physical aggression, perhaps, by limiting an individual's ability to modulate negative emotions (e.g., self-regulation of affect via internalized speech; Luria, 1961) and generate non-aggressive strategies to problem situations. Alternatively, these factors may operate hierarchically such that effective behavioral inhibition and impulse control function in a superordinate position (Clark, 1996), permitting recruitment of additional executive functions such as affect regulation, self-speech, and working memory, which may then be utilized in the modulation of aggressive behaviors (see Barkley, 1997 for review of this conceptual model in relation to ADHD). Extension of Barkley's (1997) model to the study of aggression may be a promising avenue for future research (Lynam & Henry, 2001).

In sum, evidence suggests that executive functioning deficits increase the risk for physical aggression in children and adolescents, as well as young adults. In particular, deficits in working memory, inhibitory control, organization/planning, abstract problem solving, and fluent verbal reasoning have been reported by various research teams, although use of composite EF factors by several prevented testing for specific domains of impairment. Importantly, these associations do not appear to be better accounted for by comorbid psychiatric conditions such as ADHD, nor are they the result of general intellectual functioning (IQ) or memory impairments, gender, socioeconomic status, or familial adversity. Evidence to this effect has been garnered using multiple methods of assessment, and available data imply that variations in executive functioning track meaningfully with aggressive behavior tendencies at both clinical and subclinical levels.

Internalizing problems

Deficits in concentration, working memory, inhibitory control, decision-making, sequencing, and cognitive flexibility have been documented in several studies of children and adolescents diagnosed with a clinically significant depressive disorder (e.g., Emerson et al., 2005; Forbes, Shaw, & Dahl, 2007; Halari et al., 2009; Kyte, Goodyer, & Sahakian, 2005; cf. Favre et al., 2009). Still, compared to externalizing problems, considerably less is known about the role of executive functioning in childhood and adolescent internalizing problems (Riggs et al., 2003), especially at subclinical levels.

In perhaps the most prominent neurobiological model of mood regulation to date, Mayberg (1997) posited connections between dysfunction in specific cortical-limbic circuits (i.e., dorsal, ventral, and rostral cingulate compartments) and various symptoms of depression. Considering the complexity of depressive illness and its numerous clinical manifestations, it made sense to conceptualize its neuroanatomical substrate as a widely distributed network rather than a unitary "mood regulation center," per se. Mayberg (1997) discussed this in terms of the relative balance/imbalance of network compartments. Accordingly, dysfunction within the dorsal compartment – comprising dorsolateral prefrontal cortex, dorsal anterior cingulate, inferior parietal, and striatal (i.e., caudate and putamen) regions – was linked to cognitive and attention symptoms such as apathy, impaired selective attention, and inability to disengage from ruminative thoughts (Wang et al., 2008). In contrast, vegetative and somatic symptoms such as insomnia/hypersomnia, appetite disturbance, and decreased interest in sex were associated with the ventral compartment, which was hypothesized to include the hypothalamic-pituitary-adrenal (HPA) axis, as well as the insular and subgenual cingulate cortices and portions of the brainstem. Finally, with its documented role in error detection and response modulation (e.g., Allman, Hakeem, Erwin, Nimchinsky, & Hof, 2001), the anterior or rostral cingulate cortex was postulated to serve as a modulator of functioning within and across dorsal and ventral regions. Although not explicitly an executive function account of depression, this model clearly implicates EF deficits related to self-monitoring, initiation, and inhibition of undesired response tendencies, among others, as central to mood dysregulation.

In one of the earliest larger-scale investigations of neuropsychological functioning and internalizing psychopathology, Kusché, Cook, and Greenberg (1993) examined EFs [i.e., Trails A & B (Reitan, 1979) and Stroop Color and Word Test (Golden, 1978)], as well as several other cognitive abilities, in a community sample of 305 school-age children (M_{age} = 8 years). Participants were classified, based on teacher- and self-report ratings, into four sub-groups: 1) anxiety, 2) externalizing, 3) comorbid anxiety and externalizing, and 4) nonpathological controls. Executive functions in all three psychopathological groups were significantly less well-developed than controls; however, levels of EF did not differ reliably across anxiety, externalizing, and comorbid groups. These results were interpreted as evidence that childhood "frontal-lobe dysfunction" represents a non-specific vulnerability factor that increases risk for a wide variety of emotional and behavioral problems by hindering one's ability to modulate heightened affective states (cf. Stordal et al., 2005).

Nigg, Quamma, Greenberg, and Kusché (1999) followed up on the previous investigation with a two-year longitudinal study looking at early school-age (6 – 8 years) executive functions as predictors of teacher-reported psychosocial functioning. Unlike the vast majority of neuropsychological research, this group's use of a prospective longitudinal design allowed them to control for time 1 emotional/behavioral problems, thereby affording them the opportunity to estimate change in psychosocial outcomes as a function of initial EF levels. General intelligence and reading ability were also included as covariates. Results revealed significant inverse longitudinal relations between inhibitory control (as measured by the Stoop Color-Word Interference Test; Golden, 1978) and externalizing but not internalizing problems. In contrast, verbal fluency proved to be the only EF construct negatively predictive of future internalizing problems.

Riggs and colleagues (2003) also adopted a two-year longitudinal approach in their study of concurrent and prospective links between two EF constructs (i.e., inhibitory control [The Stroop Test; Golden, 1981] and sequencing ability [Trailmaking Test; Reitan, 1971) and psychosocial functioning. Sixty school-age children (M_{age} = 7 years, 11 months) participated in this study. Utilizing both parent- and teacher-reports of internalizing and externalizing behavior problems, Riggs et al. (2003) found no significant concurrent relations between EF measures and behavioral outcomes. However, in terms of prospective relations, time 1 inhibition predicted subsequent teacher-reported decreases in externalizing problems, as well as parent-reported declines in both internalizing and externalizing behaviors. The longitudinal pattern associated with sequencing ability was more variable as it inversely predicted time 2 externalizing (according to teachers) and time 2 internalizing (according to parents).

In a more recent investigation, Martel and colleagues (2007) examined associations between several aspects of EF and psychosocial functioning in a high-risk sample of adolescents. Despite utilizing a relatively extensive battery of EF tasks including measures of working memory, set shifting, response inhibition, alertness, interference control, naming speed, and planning, the only significant predictor of externalizing problems was response inhibition, which accounted for an additional 6% of variance explained over and above other variables. Weak associations between response inhibition and internalizing difficulties were also noted; however, inhibition accounted for very little explained variance, and dropped below statistical significance with the addition of non-executive function variables. Of note, these findings are quite different than those reported by Rhoades, Greenberg, and Domitrovich (2009), who documented significant relations between inhibitory control and internalizing but not externalizing behavior problems.

In sum, despite recognition of executive function deficits among individuals with pediatric clinical depression, EF performance patterns in relation to subclinical internalizing difficulties have been inconsistent, particularly with respect to inhibitory control. Indeed, inhibitory control has been variously associated with externalizing (but not internalizing) problems (Nigg et al., 1999), internalizing (but not externalizing) problems (Rhoades et al., 2009), and both internalizing and externalizing problems (Kusché et al., 1993; Riggs et al., 2003). Too often in EF research, contradictory findings such as these can be attributed to differential test-selection (i.e., using different tasks that purportedly measure the same construct); however, the vast majority of the studies reviewed utilized variants of the Stroop Color and Word Test (Stroop, 1935) as their measure of inhibitory functioning. Therefore, the hypothesis of assessment differences appears untenable. Likewise, informant differences (i.e., parent vs. teacher) appear to be an unlikely cause of these discrepancies considering that inhibition was associated with teacher-reported internalizing (but not externalizing) in Rhoades et al. (2009) and with teacher-reported externalizing (but not internalizing) in Nigg et al. (1999). It seems, therefore, that inhibitory control is at best a variable predictor of psychosocial functioning, both in terms of emotional and behavioral problems.

Nigg et al.'s (1999) finding of a negative longitudinal association between verbal fluency and internalizing (but not externalizing) is also notable, albeit somewhat difficult to interpret. The authors suggested that perhaps children who are less able to express themselves may be more prone to internalizing; although, they further acknowledged that the same rationale could likewise be offered for externalizing problems. Alternatively, since general intelligence was controlled statistically in their analyses, Nigg and colleagues (1999) posited that their verbal fluency measure may have served as a proxy for other constructs such as processing speed, effort, and/or cognitive flexibility. This secondary interpretation seems plausible and worthy of additional research, particularly in light of evidence implicating reduced speed of information processing as an indicator of mood dysfunction (Favre et al., 2009).

Finally, the disparity in the amount of existing research between EF and internalizing versus externalizing problems is again worth noting. There are several potential reasons for this imbalance. First, given the conceptualization of EF as a constellation of self-regulatory mechanisms, it is perhaps less clear how deficits in self-regulation may increase risk for internalizing difficulties. This may be especially true relative to aggression, rule-breaking, and other behaviors more often categorized as problems of "self-control." Second, whereas normative deceleration in rates of physical aggression across early childhood tends to correspond with relatively pronounced developmental increases in EF (Séguin & Zelazo, 2005), internalizing problems often follow a different trajectory. Prevalence rates of Major Depressive Disorder (MDD), for example, generally increase throughout childhood, not reaching adult levels until adolescence (Garber, 2000). This suggests that associations between EF and internalizing may be more complex than those recognized for externalizing problems, further complicated by the high rates of comorbidity between emotional and behavioral problems (e.g., Lilienfeld, 2003). Additional research would be useful to clarify the nature of these putative associations, particularly if conducted within a framework wherein internalizing and externalizing psychosocial difficulties were modeled simultaneously to accommodate both shared and distinct features.

Current study

The current study was designed to assess empirically the structure and organization of executive functions in a large, nationally-representative sample of children and adolescents who participated in the NIH Study of Normal Brain Development, as well as to explore concurrent associations between EF and subclinical emotional and behavioral problems. Developmental differences in relations between EF and psychosocial functioning were also investigated by dividing the sample into age-based sub-groups.

A latent variable modeling approach was utilized throughout this study in order to minimize the negative effects of task impurity by statistically extracting common variance across theoretically similar manifest variables. Specifically, three latent executive function factors were examined: 1) working memory, 2) shifting, and 3) verbal fluency. The inclusion of a latent verbal fluency factor had not been attempted by previous research teams, and therefore, represents an important addition to the literature. Additionally, crystallized verbal intelligence and processing speed variables were included as non-executive controls in order to examine their putative contributions to the latent factor structure of EF. Unfortunately, an inhibitory control factor was unable to be constructed in the current study due to the unavailability of performance-based measures of inhibitory control in the available data set.

The five primary objectives of the current study were as follows:

Objective 1

Model the latent factor structure of EF. A series of confirmatory factor analyses (CFA) were conducted to determine empirically the best-fitting model for the available executive function data. One-, two-, and three-factor models were tested, and their respective fit indices were compared to establish the preferred latent variable structure. The best-fitting model was retained for subsequent analyses.

Objective 2

Examine the effects of crystallized verbal intelligence and processing speed on the latent factor structure of EF. In order to account for variance related to crystallized verbal intelligence and processing speed, separate confirmatory factor analyses were conducted with manifest EF variables programmed to cross-load on both their intended latent EF factor, as well as the control variable. This method allowed the putative effects of crystallized verbal intelligence and processing speed to be accounted for in their respective models.

Objective 3

Model the latent factor structure of subclinical emotional/behavioral problems. Prior to investigating latent associations between EF and psychosocial functioning, it was necessary to determine empirically the best-fitting model to account for the available emotional/behavioral problems data. Therefore, a series of confirmatory factor analyses were conducted to determine which of several potential configurations best represented the data.

Objective 4

Investigate latent associations between EF factors and subclinical emotional/behavioral problems. Having previously established the best-fitting EF and psychosocial functioning models, respectively, additional confirmatory factor analyses were then conducted to test the fit of all available EF and emotional/behavioral problems manifest indicators within a single model, with and without inclusion of a latent age factor.

Objective 5

Investigate developmental differences in associations between latent EF factors and subclinical emotional/behavioral problems. In order to test for developmental differences in associations between EF and psychosocial functioning, age-based sub-groups were created to facilitate comparisons. Next, measurement invariance was tested to determine comparability of latent constructs across age-groups. Finally, cross-group descriptive comparisons were conducted.

CHAPTER 3

Method

Recruitment and screening

The current investigation made use of publically-accessible data collected as part of the first wave of the National Institutes of Health (NIH) MRI Study of Normal Brain Development. The NIH MRI Study of Normal Brain Development was designed to collect behavioral, neuropsychological, and neuroimaging (e.g., anatomic MRI, diffusion tensor imaging) data from a large, nationally-representative sample of healthy children and adolescents (Evans, 2006; Waber et al., 2007). Over 500 individuals ranging in age from birth through 18 years participated in the initial data collection of this multi-wave, multi-site, on-going longitudinal project.

Recruitment procedures were population-based, involving stratification of the sample by gender, race, and socioeconomic status according to the 2000 United States census and screening for medical, neurological, genetic, and psychiatric conditions. Moreover, a number of exclusion criteria were utilized to ensure that the sample was generally representative of healthy children and adolescents (see Table 1). Of particular significance was the exclusion of individuals with Child Behavior Checklist (CBCL) subscale scores ≥ 70, as this limited the sample to individuals without clinically significant emotional or behavioral problems, according to parental report. Individuals with full scale intelligence quotient (IQ) scores < 70 were also excluded. A comprehensive description of sampling procedures has been provided by Evans (2006) and Waber et al. (2007), and can also be found on the Pediatric MRI Data Repository website (http://www.bic.mni.mcgill.ca/nihpd/info).

Table 1.

Exclusionary Criteria

Category	Specific criteria
Demographic	Children of parents with limited English proficiency. Adopted children excluded due to inadequate family histories.
Pregnancy, birth and perinatal history	Intra-uterine exposures to substances known or highly suspected to alter brain structure or function (certain medications, any illicit drug use, smoking > ½ pack per day or > 2 alcoholic drinks per week during pregnancy); Hyperbilirubinemia requiring transfusion and/or phototherapy (> 2 days); gestational age at birth of < 37 weeks or > 42 weeks; multiple birth; delivery by high forceps or vacuum extraction; infant resuscitation by chest compression or intubation; maternal metabolic conditions (e.g., phenylketonuria, diabetes); pre-eclampsia; serious obstetric complications; general anesthetic during pregnancy/delivery; C-section for maternal or infant distress
Physical/ medical or growth	Current height or weight < 3rd percentile or head circumference < 3rd percentile by National Center for Health Statistics 2000 data (charts at http://www.cdc.gov/nchs/about/major/nhanes/growthcharts/charts.htm); history of significant medical or neurological disorder with CNS implications (e.g., seizure disorder, CNS infection, malignancy, diabetes, systemic rheumatologic illness, muscular dystrophy, migraine or cluster headaches, sickle cell anemia, etc.); history of closed head injury with loss of consciousness > 30 min or with known diagnostic imaging study abnormalities; systemic malignancy requiring chemotherapy or CNS radiotherapy; hearing impairment requiring

Table 1 (continued)

Exclusionary Criteria

Category	Specific criteria
Physical/ medical or growth (cont.)	intervention; significant visual impairment requiring more than conventional glasses (strabismus, visual handicap); metal implants (braces, pins) if likely to pose safety or artifact issues for MRI; positive pregnancy test in subject.
Behavioral/ psychiatric	Current or past treatment for language disorder (simple articulation disorders not exclusionary); lifetime history of Axis I psychiatric disorder (except for simple phobia, social phobia, adjustment disorder, oppositional defiant disorder, enuresis, encopresis, nicotine dependency); any CBCL subscale score ≥ 70; WASI IQ < 70; Woodcock-Johnson Achievement Battery subtest score < 70; current or past treatment for an Axis I psychiatric disorder.
Family history	History of inherited neurological disorder; history of mental retardation caused by non-traumatic events in any first-degree relative; one or more first degree relatives with lifetime history of Axis I psychiatric disorders; schizophrenia, bipolar affective disorder, psychotic disorder, alcohol or other drug dependence, obsessive compulsive disorder, Tourette’s disorder, major depression, attention deficit hyperactivity disorder or pervasive developmental disorder.
Neuro examination	Abnormality on neurological examination (e.g., hypertonia, hypotonia, reflex asymmetry, visual field cut, nystagmus, and tics).

From Waber et al. (2007). The NIH MRI study of normal brain development: Performance of a population based sample of healthy children aged 6 to 18 years on a neuropsychological battery. *Journal of the International Neuropsychological Society, 13,* 729-746.

Participants

A total of 352 children and adolescents (184 female; 168 male) ranging in age from 7 to 18 years (*M* = 11.43 years, *SD* = 3.43) comprised the final sample for the current study. Children younger than 7 years of age were excluded due to substantial differences in the test batteries employed. Sample demographic characteristics are depicted in Tables 2 and 3, and general intelligence quotient (IQ) estimates are provided in Figure 1.

Table 2.

Age Distribution

Age, years	Frequency (%)	Age, years	Frequency (%)
7	55 (15.6%)	13	26 (7.4%)
8	36 (10.2%)	14	23 (6.5%)
9	38 (10.8%)	15	20 (5.7%)
10	35 (9.9%)	16	22 (6.3%)
11	27 (7.7%)	17	24 (6.8%)
12	31 (8.8%)	18	15 (4.3%)

Table 3.

Sample Demographic Characteristics

Characteristic	Distribution (%)
Sex (% female)	184 (52.3%)
Handedness (% right-handed)	317 (90.1%)
Family income:	
Low (less than $35,000/year)	85 (24.1%)
Medium ($35,000 to $75,000/year)	138 (39.2%)
High (more than $75,000/year)	129 (36.6%)
Racial/ethnic group:	
White	260 (73.9%)
African-American	28 (8.0%)
Asian	4 (1.1%)
American Indian/Alaskan Native	1 (0.3%)
Hispanic	42 (11.9%)
Biracial/Multiracial	17 (4.8%)
Geographic region:	
East	104 (29.5%)
Midwest	132 (37.5%)
West	116 (33.0%)

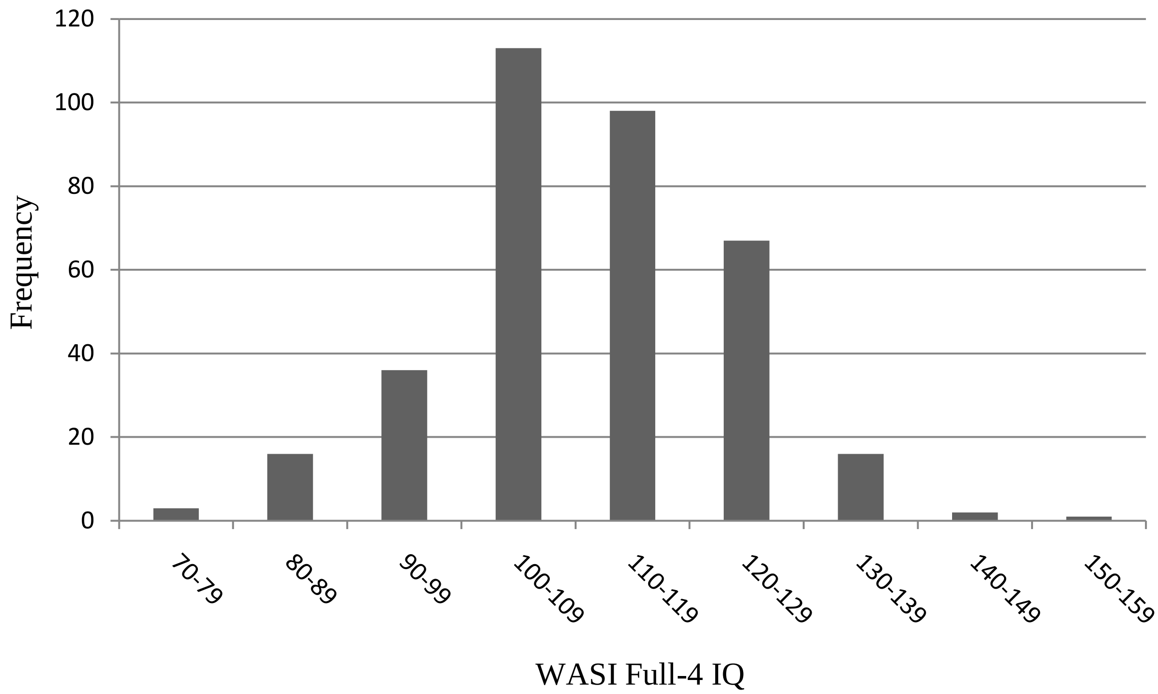

Figure 1. WASI full-4 IQ estimates for the full sample.

Procedures

Following successful completion of screening measures, participants were invited to the study site for clinical, behavioral, and neuroimaging data collection. The sheer breadth of data sought precluded the use of overly lengthy test batteries. Therefore, clinical and behavioral test selection was limited to "well standardized, clinically interpretable tests with well-established psychometric properties" (Evans, 2006, p. 186) that could be administered within a single, 2 to 3 hour testing session. Neuroimaging data were not considered in the current investigation; however, interested readers are directed to the Pediatric MRI Data Repository website (http://www.bic.mni.mcgill.ca/nihpd/info) for more information.

Data for this study were obtained directly from the purveyors of the Pediatric MRI Data Repository, in accordance with outlined procedures for data access to qualified researchers. No identifying information was accessible to the author. The current study was approved by the University of Minnesota's Institutional Review Board.

Measures

Executive functions

Cambridge Neuropsychological Test Battery (CANTAB) (CeNeS, 1998). The CANTAB is an automated battery of mostly non-verbal neuropsychological tests presented visually, using a portable touch screen computer (e.g., Luciana, 2003; Luciana & Nelson, 2002). The following three subtests were examined in the current study:

1. *Spatial Span (SSP).* This task measures memory for a sequence of visually presented information. Participants viewed a lighted sequence after which they were asked to reproduce that sequence by touching boxes on the computer screen in the order in which the lights were presented. The task begins with a sequence of two lighted boxes and increases to a maximum sequence of nine boxes. There is some evidence suggesting that this task involves the right ventrolateral prefrontal cortex (Robbins, 1996). Total spatial span (i.e., the longest sequence successfully recalled) served as the dependent variable.
2. *Spatial Working Memory (SWM).* This self-ordered search task required participants to carry out an organized search of various containers (i.e., "boxes") to find hidden tokens. The total number of containers is increased to

a maximum of eight as the test progresses. This task is considered a measure of spatial working memory (analogous to verbal working memory tasks such as Digit Span) and is thought to activate both the dorsal and ventral regions of the PFC (Owen, Evans, & Petrides, 1996). Measures of between-trial and within-trial search errors (i.e., revisiting boxes previously shown to be empty and/or revisiting boxes in which a token had already been found) were obtained.

3. *Intradimensional/Extradimensional Set Shift (IED).* The IED task is a measure of discrimination and reversal learning that requires the participant to use feedback to learn response contingencies. Specifically, an individual is presented with two stimulus patterns and instructed to choose the correct pattern. However, like the Wisconsin Card Sorting Test (Grant & Berg, 1948), no explicit instructions are provided regarding how to select the correct option. Thus, participants must use feedback (correct/incorrect) to discern the appropriate rule, and then apply that rule in subsequent trials in order to determine which answer choice is correct. In addition, the selection rule changes after six correct responses, thus requiring the participant to adapt their strategy accordingly. Both dorsolateral and orbitofrontal regions of the PFC are thought to be recruited in completing this task (e.g., Dias, Robbins, & Roberts, 1996). Measures of total errors and total number of stages completed were obtained.

Digit Span. This task of verbal working memory required participants to listen and repeat random digit strings of increasing length. During the forward condition (DS_F), participants were instructed to repeat digits in the order presented. In the more difficult backward condition (DS_B), participants were asked to repeat the digits in reverse order. Depending on their ages, participants were administered either the Wechsler Intelligence Scale for Children – Third Edition (WISC-III; ages 7 years – 16 years, 11 months) or the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; ages 17 years and older) version of the Digit Span task. Raw digit span scores from both forward and backward conditions served as the dependent variables.

Verbal fluency. The verbal fluency tasks used in this study were patterned after the NEPSY (Korkman, Kirk, & Kemp, 1998) verbal fluency test and required language-mediated working memory, reasoning, and inhibitory controls skills (Baldo, Shimamura, Delis, Kramer, & Kaplan, 2001), and consisted of both semantic and phonetic components. The semantic component (VF_S) required participants to name as many animals and as many kinds of food/drink as possible, given one minute to respond for each category. The dependent variable for this condition was the total number of words generated during the animals and food/drink trials. In the phonetic component (VF_P), participants were asked to name as many words as possible that begin with particular letters (F, A, S). Again, participants had one minute to respond to each letter. The dependent variable for this condition was the total number of words generated across all three trials.

Behavior Rating Inventory of Executive Functions (BRIEF) (Gioia, Isquith, Guy, & Kenworthy, 2000). The BRIEF is an 86-item parent-report questionnaire designed to assess several areas of real-world executive functioning. Domains assessed included Behavior Regulation (Inhibit, Shift, Emotional Control subscales) and Metacognition (Initiate, Working Memory, Plan/Organize, Organization of Materials, Monitor subscales). For the purpose of this study, raw scores from the Working Memory (e.g., "When given three things to do, remembers only the first or last;" "Has a short attention span;" "Has trouble concentrating on chores, schoolwork, etc.") and Shift (e.g., "Becomes upset with new situations;" "Tries the same approach to a problem over and over even when it does not work;" "Acts upset by a change in plans") subscales served as the dependent variables.

Intellectual functioning

Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999). The WASI is a brief, 4-subtest measure of intellectual functioning that yields estimates of verbal (Vocabulary, Similarities) and perceptual/nonverbal skills (Block Design, Matrix Reasoning), as well as a Full Scale IQ estimate. As discussed above, individuals whose Full Scale IQ was below 70 (i.e., 2 standard deviations below the mean) were excluded from participation in the NIH MRI Study of Normal Brain Development. Vocabulary subtest raw score was used as an estimate of verbal intelligence in the current study.

Processing speed

Wechsler Intelligence Scale for Children-Third Edition (WISC-III): Coding (Wechsler, 1991). The WISC-III Coding subtest is a test of information processing speed in which participants (ages 7 years – 16 years, 11 months) were instructed to manually decode numbers into symbols according to a given translation key as quickly and accurately as possible, within a pre-specified time limit. Raw scores used in this study represent the total number of accurately decoded symbols.

Wechsler Adult Intelligence Scale-Third Edition (WAIS-III): Digit Symbol (Wechsler, 1997). The WAIS-III Digit Symbol subtest is the adult analogue of the WISC-III Coding subtest and was administered to participants 17 years of age and older. The total number of accurately decoded symbols served as the dependent variable.

Psychosocial Functioning

Child Behavior Checklist (CBCL) (Achenbach, 2001). The CBCL is a 113-item parent-report questionnaire for assessing children's emotional and behavioral problems. The CBCL yields scores for 8 subscales (withdrawn-depressed, anxious-depressed, somatic problems, aggressive behavior, rule-breaking behavior, attention problems, social problems, thought problems), as well as 2 supra-ordinate scales (Internalizing, Externalizing). As discussed previously, individuals with a *T*-score greater than 70 (i.e., 2 standard deviations above the mean) on any CBCL subscale or supra-ordinate scale were excluded from participation in the NIH MRI Study of Normal Brain Development. Raw subscale scores were used in this study.

Data Analysis

Preliminary data analyses were conducted using SPSS 17.0 (2008) and PASW Statistics 18.0.0 (2009). Confirmatory factor analyses were conducted using LISREL 8.80 (Joreskog & Sorbom, 2007). Variance/covariance matrices were input to LISREL.

Missing data

Missing data are problematic in latent variable modeling, especially when dealt with using traditional methods such as pairwise deletion, listwise deletion, or mean-replacement (Graham, Cumsille, & Elek-Fisk, 2003; McDonald & Ho, 2002). In the current study, missing data accounted for no greater than 2-3% of most variables of interest, with the exceptions of approximately 10% missing for both phonetic and semantic verbal fluency measures and 18% missing for rule-breaking and withdrawn-depressed CBCL subscales. Missing data were imputed using Full Information Maximum Likelihood (FIML) procedures (LISREL-PRELIS 8.80; 200 iterations/convergence criterion = 0.00001). Subsequent analyses were performed using fully imputed data.

Goodness-of-fit indices

Latent variable statistical analyses attempt to recreate the variance/covariance information provided by the researcher in accordance with a pre-specified model. Unlike traditional statistical methods, model-fitting programs such as LISREL utilize iterative, maximum likelihood (ML) estimation procedures to generate "parameter estimates that maximize the probability of observing the available data if the data were collected from the same population again" (Brown, 2006, p. 73). Several goodness-of-fit indices are then utilized to determine how well the implied parameter estimates represent the available data, as well as to compare across hypothesized models to determine empirically the best-fitting option. In general, best practice guidelines recommend the use of a combination of *absolute* (i.e., a measure of model fit without reference to a null model) and *relative* (i.e., a measure of model fit in reference to a null model in which no correlations are predicted among manifest indicators) fit indices, in addition to the most commonly used chi-square statistical fit index, to establish model fit (Brown, 2006). For the purposes of the current investigation, the following fit indices were considered:

Chi-Square (χ^2). The chi-square statistic provides an index of model fit based on the null hypothesis that the parameter estimates generated according to a given model's specifications are identical to the available data. Thus, failure to reject the null hypothesis, as determined by a non-significant chi-square statistic relative to the chi-square distribution ($p > .05$), is indicative of good model fit. Conversely, a significant chi-square statistic ($p < .05$) suggests that the tested model provides a poor fit because the implied parameter estimates differ significantly from the data. Despite being the most frequently reported statistic in latent variable modeling, it is now widely recognized that the chi-square fit statistic is unduly sensitive to sample size, thus rendering it almost meaningless as a stand-alone fit index, particularly when applied to large samples (Brown, 2006).

Root Mean Square Error of Approximation (RMSEA). The RMSEA is an absolute fit index that yields an estimate of model misfit per degree of freedom, without reference to a hypothetical null model. Thus, as an estimate of misfit, smaller values reflect better model fit. In general, RMSEA values are interpreted according to the following guidelines: 0.0 = exact/perfect fit; 0.01 – 0.05 = close fit; 0.05 – 0.08 = acceptable fit; 0.08 – 0.10 = mediocre fit; and, > 0.10 = poor fit (Hu & Bentler, 1999; Brown, 2006).

Comparative Fit Index (CFI). The CFI is a relative fit index in which a given model is compared to a null model with manifest interrelations fixed to zero. CFI values are generally interpreted according to the following guidelines: 1.0 = exact/perfect fit; 0.95 – 0.99 = close fit; 0.90 – 0.95 = acceptable fit; 0.85 – 0.90 = mediocre fit; and, < 0.85 = poor fit (Brown, 2006).

Non-Normed Fit Index (NNFI). Like the CFI, the NNFI (also known as the Tucker-Lewis Index [TLI]) is a relative fit index in which a tested model is compared to a null model wherein relations among manifest indicators are fixed to zero. Moreover, NNFI values are generally interpreted in the same manner as CFI values (i.e., 1.0 = exact/perfect fit; 0.95 – 0.99 = close fit; 0.90 – 0.95 = acceptable fit; 0.85 – 0.90 = mediocre fit; and, < 0.85 = poor fit [Brown, 2006]).

Model comparison

Nested Chi-Square Difference Test ($\Delta\chi^2$). Models are considered nested if they differ only with respect to the specified pattern of parameter estimates (i.e., the same manifest indicators and latent factors are tested and only the pattern of fixed/freed parameters differ; Brown, 2006). A nested chi-square difference test is conducted as follows:

$$\Delta\chi^2 = \chi^2_{\text{model A}} - \chi^2_{\text{model B}} \text{ with } df_{\text{Model A}} - df_{\text{Model B}}$$

where Model A is the more restricted model, Model B is the less restricted model, and *df* is equal to the degrees of freedom in each model. Significance is subsequently determined by comparing the resultant difference to the chi-square distribution at the level of the resultant difference in degrees of freedom. A significant chi-square value indicates that the change in parameter specifications across models significantly worsened model fit.

Akaike Information Criterion (AIC). In contrast to the chi-square difference test, the AIC is used to compare non-nested models (i.e., models with different numbers of latent variables). Lower AIC values indicate better relative model fit (Brown, 2006). The AIC is calculated as follows:

$$\text{AIC} = \chi^2 + 2df.$$

CHAPTER 4

Results

Preliminary Analyses

Descriptive results

Descriptive information for EF and psychosocial functioning variables is depicted in Tables 4 and 5, respectively. Two EF variables (i.e., Spatial Working Memory – Within Trial Errors and Intradimensional/Extradimensional Shift – Stages Completed) were found to be significantly skewed (skewness = 3.68 and -2.61, respectively), and thus were excluded from subsequent analyses. All other EF variables were relatively normally distributed. Psychosocial functioning variables were also within the generally acceptable range of skewness (i.e., +/- 2; e.g., Tabachnick & Fidell, 1996).

Table 4.

Descriptive Statistics for Executive Function Measures

Measure	*M*	*SD*	Min	Max	Skewness	Kurtosis
SSP	5.93	1.71	0	9	<-0.01	-0.26
SWM (BTE)	32.66	21.33	0	97	0.28	-1.02
SWM (WTE)	1.74	2.89	0	24	3.68	20.50
Digit Span – Forward	8.59	2.12	4	15	0.28	-0.58
Digit Span – Backward	5.57	2.02	2	12	0.53	-0.11
BRIEF Working Memory	13.83	3.57	10	28	0.89	0.21
IED (Errors)	23.48	14.05	0	69	0.43	-0.59
IED (Stages Completed)	7.92	1.55	0	9	-2.61	9.57
BRIEF Shift	10.35	2.30	8	17	0.84	-0.24
Verbal Fluency (Phonemic)	22.94	11.09	0	61	0.29	-0.16
Verbal Fluency (Semantic)	33.64	11.24	0	87	0.54	0.88

Note. SSP = Spatial Span, SWM (BTE) = Spatial Working Memory (Between Trial Errors), SWM (WTE) = Spatial Working Memory (Within Trial Errors), IED = Intradimensional/Extradimensional Shift.

Table 5.

Descriptive Statistics for CBCL Psychosocial Functioning Measures

Measure	*M*	*SD*	Min	Max	Skewness	Kurtosis
Externalizing	3.43	3.52	0	17	1.39	1.75
Internalizing	3.32	3.22	0	17	1.11	1.06
Aggressive Behavior	2.52	2.72	0	14	1.33	1.40
Anxious-Depressed	1.65	1.81	0	8	1.24	1.30
Attention Problems	1.77	2.19	0	12	1.61	2.62
Rule-Breaking	1.00	1.34	0	9	1.94	5.69
Social Problems	0.99	1.38	0	8	1.94	4.52
Somatic Complaints	0.80	1.23	0	6	1.81	3.24
Thought Problems	0.92	1.34	0	6	1.86	3.30
Withdrawn-Depressed	0.86	1.24	0	6	1.76	3.12

Intraconstruct correlations

Zero-order correlation coefficients were calculated separately for EF and psychosocial functioning variables (see Tables 6 and 7, respectively). With the exception of nonsignificant associations between the BRIEF Shift subscale and Digit Span – Forward ($r = -.05$) and Backward ($r = -.08$) conditions, all EF variables were significantly intercorrelated. Additionally, all psychosocial functioning variables were significantly intercorrelated at $p < .001$, except for the correlation between somatic complaints and attention problems ($p < .01$).

Table 6.

Intercorrelations among Executive Function Measures, Age, Vocabulary, and Processing Speed

Measure	1.	2.	3.	4.	5.	6.
1. SSP	-					
2. SWM (BTE)	-.48***	-				
3. DS – F	.40***	-.43***	-			
4. DS – B	.47***	-.52***	.51***	-		
5. BR – WM	-.17**	.21***	-.21***	-.20***	-	
6. IED (Errors)	-.25***	.32***	-.19***	-.23***	.12*	-
7. BR – Shift	-.13*	.12*	-.05	-.08	.45***	.14*
8. VF – P	.51***	-.51***	.45***	.53***	-.26***	-.20***
9. VF – S	.46***	-.52***	.42***	.47***	-.22***	-.27***
10. Age	.66***	-.63***	.46***	.60***	-.22***	-.27***
11. Voc	.61***	-.64***	.56***	.59***	-.26***	-.40***
12. PS	.58***	-.58***	.42***	.55***	-.27***	-.38***

* $p < .05$, ** $p < .01$, *** $p < .001$.

Note. SSP = Spatial Span, SWM (BTE) = Spatial Working Memory (Between Trial Errors),DS-F = Digit Span (Forward), DS-B = Digit Span (Backward), BR-WM = BRIEF Working Memory subscale, IED = Intradimensional/Extradimensional Shift, BR-Shift = BRIEF Shift subscale, VF-P = Verbal Fluency (Phonemic), VF-S = Verbal Fluency (Semantic), Voc = WASI Vocabulary, PS = Processing Speed (Coding/Digit Symbol).

Table 6 (continued).

Intercorrelations among Executive Function Measures, Age, Vocabulary, and Processing Speed

Measure	7.	8.	9.	10.	11.	12.
7. BR – Shift	-					
8. VF – P	-.09	-				
9. VF – S	-.05	.69***	-			
10. Age	-.10	.71***	.62***	-		
11. Voc	-.12*	.75***	.70***	.83***	-	
12. PS	-.14**	.56***	.54***	.74***	.69***	-

* $p < .05$, ** $p < .01$, *** $p < .001$.

Note. BR-Shift = BRIEF Shift subscale, VF-P = Verbal Fluency (Phonemic), VF-S = Verbal Fluency (Semantic), Voc = WASI Vocabulary, PS = Processing Speed (Coding/Digit Symbol).

Table 7.

CBCL Subscale Intercorrelations

Measure	1.	2.	3.	4.	5.	6.	7.	8.
1. Aggressive Behavior	-							
2. Anxious-Depressed	.41	-						
3. Attention Problems	.48	.25	-					
4. Rule-Breaking	.59	.20	.48	-				
5. Social Problems	.47	.45	.46	.32	-			
6. Somatic Complaints	.29	.29	.15**	.22	.31	-		
7. Thought Problems	.34	.37	.45	.37	.36	.26	-	
8. Withdrawn-Depressed	.34	.44	.31	.20	.45	.26	.25	-

**$p < .01$.

Note. All correlations significant at $p < .001$ unless otherwise noted.

Primary Analyses

Objective 1: Model the latent factor structure of EF

A series of confirmatory factor analyses (CFA) were conducted to determine empirically the best-fitting model for the available executive function data[2,3]. One-, two-, and three-factor models were tested, and their respective fit indices were compared to establish the preferred latent variable structure. In addition, completely standardized factor loadings[4] were examined to ensure that associations were not only statistically significant, but also of sufficient magnitude to suggest that they were, in fact, substantively meaningful (i.e., salient) to the model. Parameter estimates of .40 or greater are generally considered salient (Brown, 2006). Finally, to clarify whether an independent or an interrelated conceptualization of latent factors more accurately reflected the data, both independent and intercorrelated (i.e., full) three-factor models were examined.

All manifest indicators loaded significantly ($p < .05$) and in expected directions on their respective latent factors. Nonetheless, examination of completely standardized factor loadings called into question the salience of BRIEF working memory (.31) and

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[2] The following variables were reverse-coded for ease of interpretation: Spatial Working Memory – Between Trial Errors, BRIEF Shift and Working Memory subscales, and Intradimensional Extradimensional Shift – Errors.
[3] Residuals were allowed to correlate to accommodate shared-method variance. Freeing these error parameters was justified given that the indicators involved were collected via the same method (e.g., parent-report questionnaires); therefore, correlated residual estimates likely reflected non-random covariation due to shared-method variance (Brown, 2006; Loehlin, 2004).
[4] As discussed by Brown (2006), completely standardized factor loadings are parameter estimates that have been standardized across all variables considered in a given analysis. Accordingly, these estimates can be interpreted as the correlation between a given manifest indicator and its latent factor. They may also be squared to estimate the amount of variance accounted for by a given latent factor. For example, a completely standardized factor loading of .40 suggests that approximately 16% of the variance observed in a given manifest variable is explained by the latent factor with which it is associated.

shifting (.23) subscales, neither of which appeared to contribute meaningfully to the model. Consequently, these indicators were removed from subsequent analyses.

As depicted in Table 8, the full three-factor model provided the best fit to the data, as indicated by its superior relative and absolute fit indices and significant associations among all three latent EF factors ($p < .001$; Figure 2). It should be noted that the two-factor model combining Working Memory and Shifting factors also fit the data very well; however, the three-factor model was preferred for two reasons: 1) the Root Mean Square Error of Approximation (RMSEA) 90% confidence intervals (CI) for the three-factor and two-factor models were identical (i.e., RMSEA 90% CI = .00 - .07), suggesting that the difference between them was not statistically significant, and 2) the single-indicator Shifting factor may have been more strongly associated with Working Memory due to their shared use of CANTAB measures rather than true lack of independence of constructs. A one-factor model in which all manifest indicators were loaded onto a single EF factor revealed a very poor fit, as did models wherein Verbal Fluency was combined with another EF factor. In addition, an independent three-factor model in which inter-construct latent associations were fixed at zero exhibited an extremely poor fit, suggesting that the examined latent executive function factors were, as expected, distinct yet related cognitive constructs.

Table 8.

Fit Indices for Executive Function CFA Models

Model	*df*	χ^2	AIC[a]	RMSEA[a]	NNFI[b]	CFI[b]
1. One-factor	14	56.10***	84.10	.093	.955	.970
Two-factor:						
2. Shifting = Fluency	13	27.05*	57.05	.055	.984	.990
3. Shifting = WM	13	19.92	49.93	.039	.992	.995
4. WM = Fluency	14	56.10***	84.10	.093	.955	.970
5. Independent three-factor	15	237.79***	263.79	.206	.777	.841
6. Full three-factor	**12**	**19.45**	**51.45**	**.042**	**.991**	**.995**

* $p < .05$, *** $p < .001$

[a] Lower values represent better model fit; RMSEA ≤ .05 indicates a close fit of the model.

[b] Values higher than .95 indicate a close fit of the model.

Note. $N = 352$. WM = Working Memory, AIC = Akaike Information Criterion, RMSEA = Root Mean Square Error of Approximation, NNFI = Non-Normed Fit Index/Tucker Lewis Index, CFI = Comparative Fit Index. Accepted model is in bold.

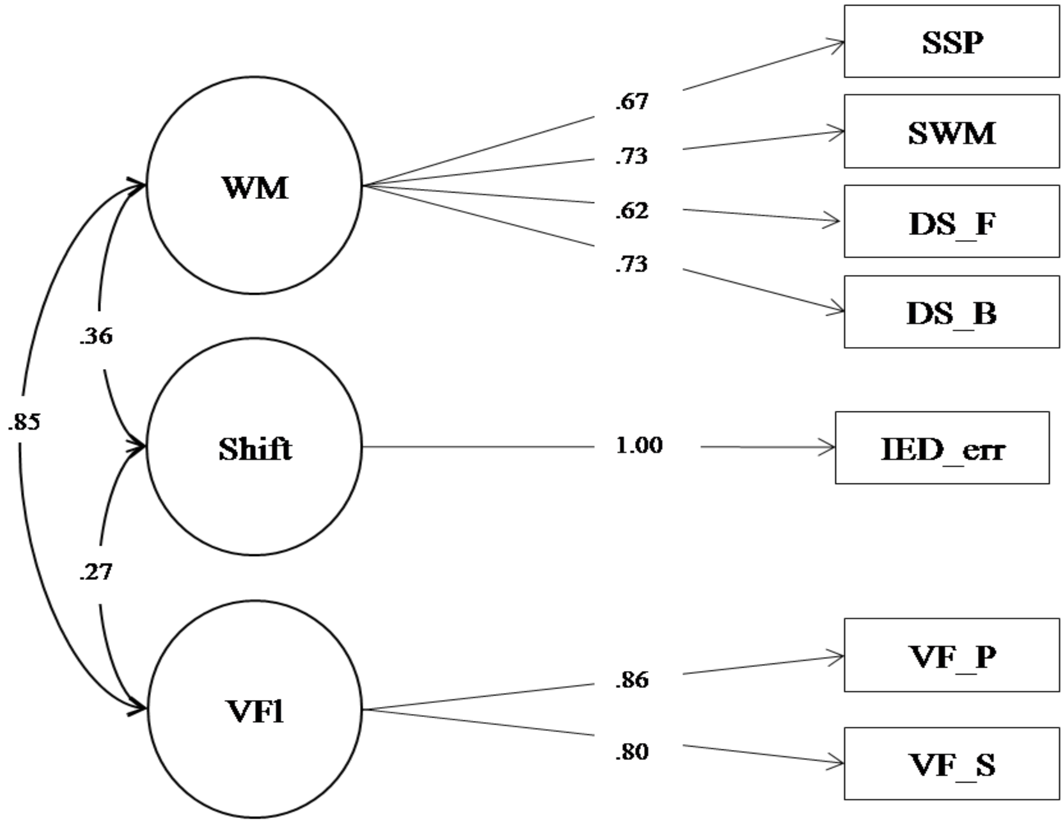

Figure 2. Confirmatory factor analysis of executive function variables. Values depicted are completely standardized factor loadings.

Objective 2: Examine the effects of crystallized verbal intelligence and processing speed on the latent factor structure of EF

Crystallized verbal intelligence. In order to account for variance related to crystallized verbal intelligence in the previously discussed full three-factor model of EF, a separate confirmatory factor analysis was conducted. First, a latent Verbal Intelligence factor was created using a single indicator of each participant's raw score on the Vocabulary subtest of the WASI (Wechsler, 1999). Manifest EF variables were then programmed to cross-load on both their intended latent EF factor, as well as the newly created Verbal Intelligence factor, thus removing the putative effects of crystallized verbal intelligence on the latent factor structure of EF (see Figure 3).

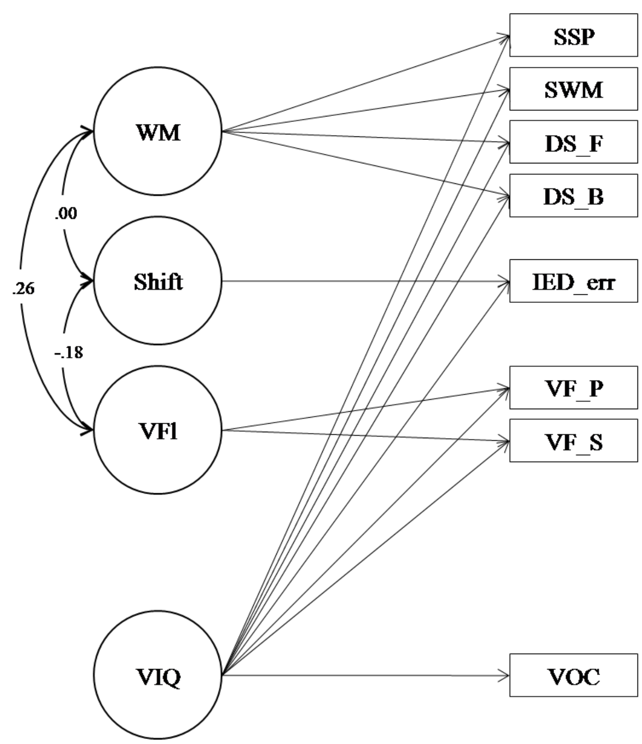

Figure 3. Confirmatory factor analysis of EF variables and verbal intelligence.

The resulting model demonstrated a close fit to the data ($\chi^2_{(12)} = 13.02$, $p = .37$; RMSEA = .016; NNFI = .999; CFI = 1.000). Examination of individual indicators revealed significant positive loadings ($p < .001$) for all EF variables on both Verbal Intelligence (see Table 9) and their respective latent EF factor. With respect to inter-construct associations, Verbal Fluency continued to demonstrate a significant positive relation with latent Working Memory ($p < .01$); however, Working Memory and Shifting factors were no longer significantly interrelated. This finding suggests that the association between working memory and shifting abilities is facilitated by verbal abilities. Interestingly, Verbal Fluency and Shifting were significantly negatively related once crystallized verbal intelligence was taken into account ($p < .01$). In other words, accounting for verbal intellectual functioning, children and adolescents with more well-developed fluent verbal reasoning abilities were also more error-prone on a set shifting task.

Processing speed. In order to account for variance related to information processing speed in the previously discussed full three-factor model of EF, a separate confirmatory factor analysis was conducted. First, a Processing Speed factor was created using a single indicator of each participant's raw score on either the WISC-III Coding or WAIS-III Digit Symbol subtest, as determined by his or her age at the time of assessment. Manifest EF variables were then programmed to cross-load on both their intended latent EF factor, as well as the newly created Processing Speed factor, thus removing the putative effects of speed of information processing on the latent factor structure of EF (see Figure 4).

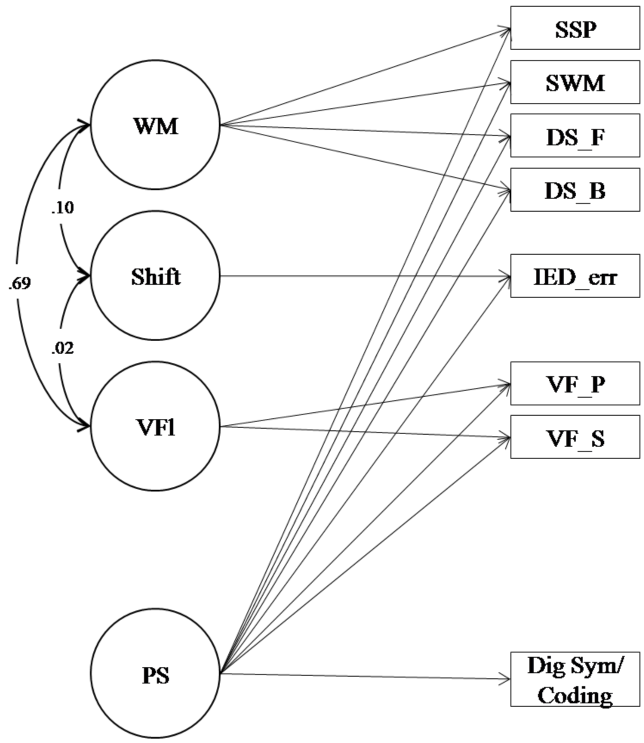

Figure 4. Confirmatory factor analysis of EF variables and processing speed.

The resulting model demonstrated a close fit to the data ($\chi^2_{(12)}$ = 16.51, p =.17; RMSEA = .033; NNFI = .995; CFI = .998). Examination of individual indicators revealed significant positive loadings ($p < .001$) for all EF variables on both Processing Speed (see Table 9) and their respective latent EF factor. With respect to inter-construct relations, Working Memory and Verbal Fluency continued to demonstrate a significant positive association ($p < .001$); however, the inclusion of processing speed resulted in non-significant associations between Shifting and both Working Memory ($p = .13$) and Verbal Fluency ($p = .71$) latent factors. This finding suggests that processing speed may be a common factor underlying associations between shifting and the other EF factors examined in this study.

Table 9.

Completely Standardized Factor Loadings of Manifest EF Indicators on Verbal Intelligence and Processing Speed Control Variables

	Verbal Intelligence		Processing Speed	
Indicator	Factor loading	*p*-value	Factor loading	*p*-value
Spatial Span	.61	< .001	.58	< .001
Spatial Working Memory	.64	< .001	.58	< .001
Digit Span (Forward)	.56	< .001	.42	< .001
Digit Span (Backward)	.59	< .001	.55	< .001
IED Shift (Errors)	.40	< .001	.38	< .001
Verbal Fluency (Phonemic)	.75	< .001	.56	< .001
Verbal Fluency (Semantic)	.70	< .001	.54	< .001

Note. IED = Intradimensional/Extradimensional Shift

Summary. Overall, examination of the effects of crystallized verbal intelligence and processing speed on the latent factor structure of executive functioning yielded several interesting results. First, both covariate models fit the data closely and improved upon the fit of the preferred Objective 1 model (i.e., the full three-factor model). Second, manifest indicators continued to exhibit significant loadings on their respective latent EF factors even when variance related to the covariates was removed. Finally, and most relevant to an understanding of the latent factor structure of EF in the current sample, inter-construct latent associations were differentially affected by the two covariates. Specifically, whereas the association between Working Memory and Verbal Fluency remained significant and positive in both models, Shifting and Working Memory were not significantly related in models accounting for crystallized verbal intelligence or processing speed. In addition, Verbal Fluency and Shifting were not significantly related when accounting for processing speed, and were negatively associated when variance related to verbal intelligence was considered.

Objective 3: Model the latent factor structure of subclinical emotional/behavioral problems

A series of confirmatory factor analyses were conducted to determine empirically the best-fitting model for the available psychosocial functioning data (i.e., Child Behavior Checklist subscales). Two models were tested initially and their respective fit indices compared to establish the preferred latent variable structure. First, Achenbach's (2001) model was examined (Figure 5, panel A). According to this configuration, rule-breaking and aggressive behavior subscales should load onto an Externalizing factor; anxious/depressed, withdrawn/depressed, and somatic complaints subscales should load onto an Internalizing factor; and, attention problems, thought problems, and social problems subscales should cross-load onto both Externalizing and Internalizing factors. The second model tested was a one-factor model in which all eight CBCL subscales were loaded onto a single latent Emotional/Behavioral Problems (E/BP) factor (Figure 5, panel B).

A

B

C

D

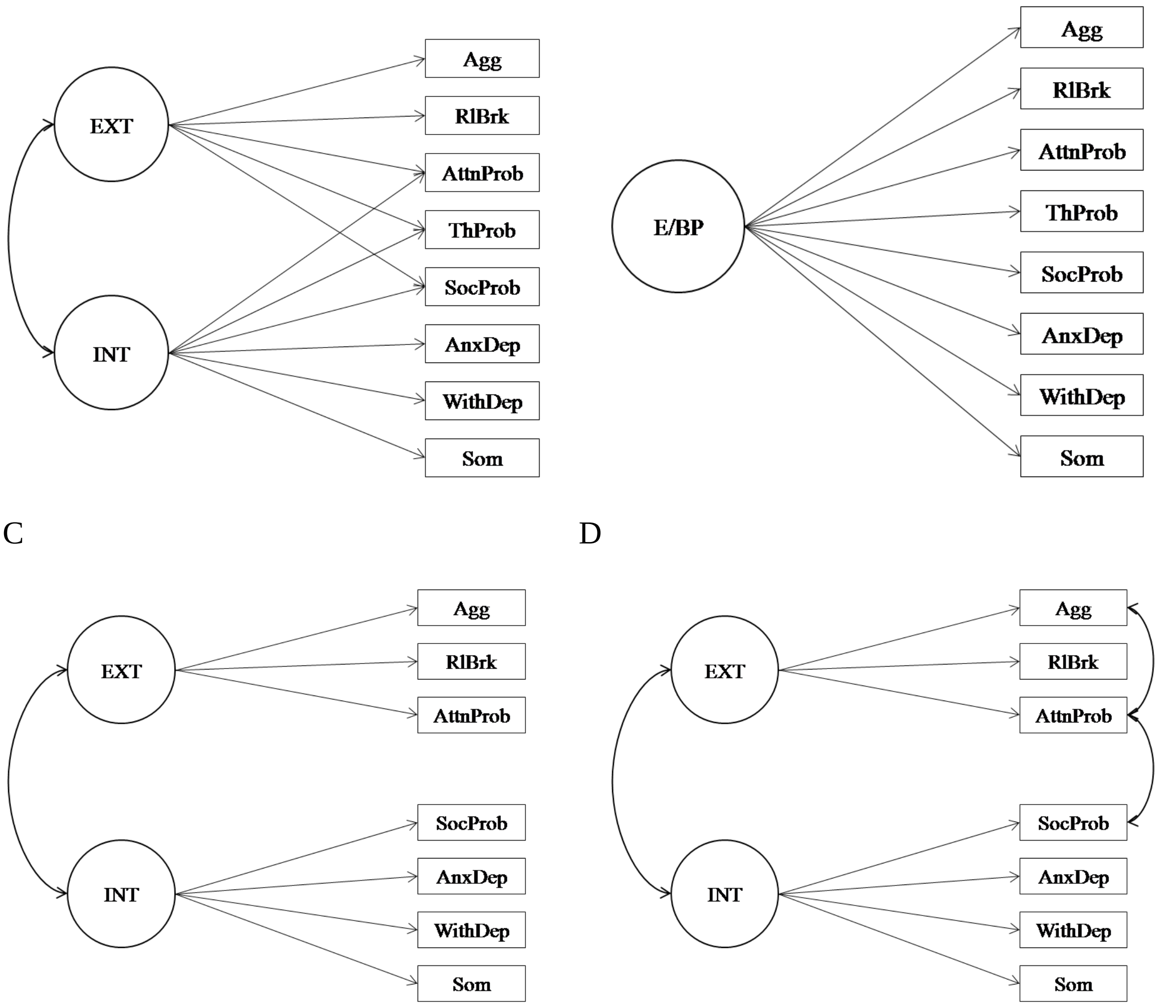

Figure 5. Configural factor models for psychosocial functioning variables.

As depicted in Table 10, the two-factor model provided a better fit to the data than the one-factor model. However, in contrast to the Achenbach (2001) model, the attention problems subscale failed to load significantly onto a latent Internalizing factor. Consequently, the factor loading between attention problems and Internalizing was removed. In addition, examination of completely standardized factor loadings revealed three non-salient (i.e., < .40) parameter estimates which were removed. As a result, the thought problems subscale was omitted and the loading from social problems onto Externalizing was deleted (Figure 5, panel C).

The modified two-factor model demonstrated a slightly improved fit over the previously discussed two-factor model; nonetheless, model fit remained generally within the mediocre range. Further examination of LISREL modification indices revealed two significantly correlated residuals (i.e., aggression – attention problems and attention problems – social problems), which were freed to accommodate shared-method variance (Figure 5, panel D). Ultimately, the final model exhibited a close fit to the data with all indicators loading significantly ($p < .001$) on their designated latent factors. As expected, the latent association between Externalizing and Internalizing was positive and significant at $p < .001$. This modified two-factor model with freed residuals was retained for subsequent analyses.

Table 10.

Fit Indices for Psychosocial Functioning CFA Models

Model	*df*	χ^2	AIC[a]	RMSEA[a]	NNFI[b]	CFI[b]
1. One-factor	20	143.83***	175.83	.133	.864	.903
2. Two-factor	16	64.95***	104.95	.093	.933	.962
3. Modified two-factor	13	45.01***	75.01	.084	.947	.967
4. Modified two-factor with freed residuals	**11**	**15.82**	**49.82**	**.035**	**.991**	**.995**

***$p < .001$

[a] Lower values represent better model fit; RMSEA ≤ .05 indicates a close fit of the model.

[b] Values higher than .95 indicate a close fit of the model.

Note. $N = 352$. AIC = Akaike Information Criterion, RMSEA = Root Mean Square Error of Approximation, NNFI = Non-Normed Fit Index/Tucker Lewis Index, CFI = Comparative Fit Index. Accepted model is in bold.

Objective 4: Investigate latent associations between EF factors and subclinical emotional/behavioral problems

Having previously established the best-fitting EF and psychosocial functioning models, respectively, additional confirmatory factor analyses were then conducted to test the fit of all available EF and emotional/behavioral problems manifest indicators within a single model, with and without inclusion of a latent age factor.

Measurement model. The first model consisted of three EF latent constructs (Working Memory, Shifting, and Verbal Fluency) and two psychosocial functioning latent constructs (Externalizing and Internalizing; see Figure 6). The pattern of factor loadings and residuals was retained from previous models. Latent EF and psychosocial functioning factors were allowed to intercorrelate.

Results demonstrated a close fit to the data ($\chi^2_{(66)} = 114.48$, $p < .001$; RMSEA = .046; NNFI = .973; CFI = .980) with all manifest indicators loading significantly ($p < .001$) and in expected directions on their respective latent factors (Figure 7). In addition, all factor loadings were considered salient with completely standardized parameter estimates of > .40. Significant positive relations were observed among all three latent EF factors ($p < .001$), as well as between latent Externalizing and Internalizing factors ($p < .001$). Furthermore, Externalizing was significantly negatively associated with Working Memory ($p < .01$) and Verbal Fluency ($p < .01$) factors. In addition, a trend-level negative association was found between Working Memory and Internalizing ($p = .08$). Shifting demonstrated a marginal trend-level negative association with Externalizing ($p =$

.10), but was not associated with Internalizing (p = .60). A marginal negative relation was also noted between Verbal Fluency and Internalizing (p = .13).

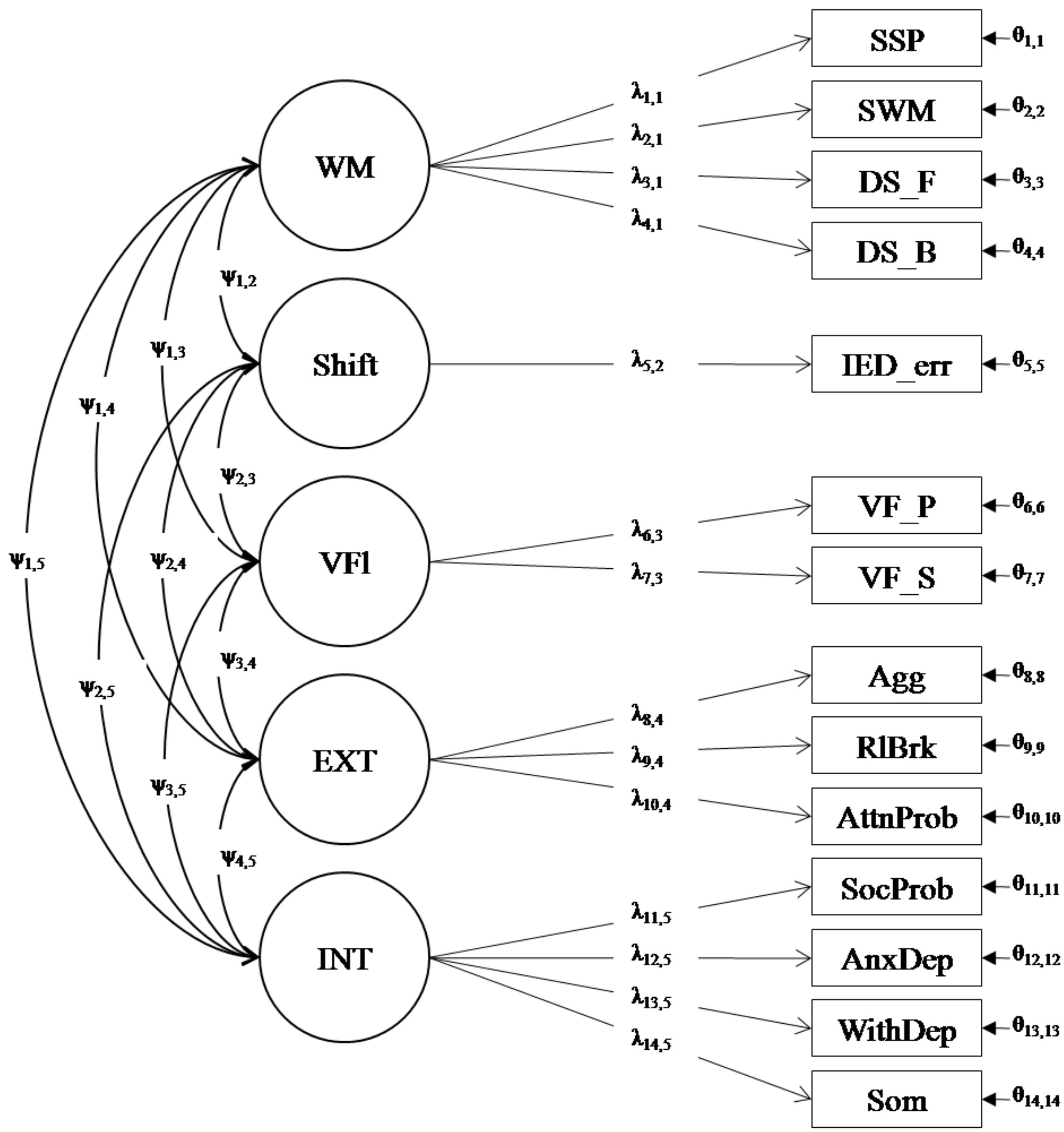

Figure 6. Configural model for latent EF and psychosocial functioning constructs.

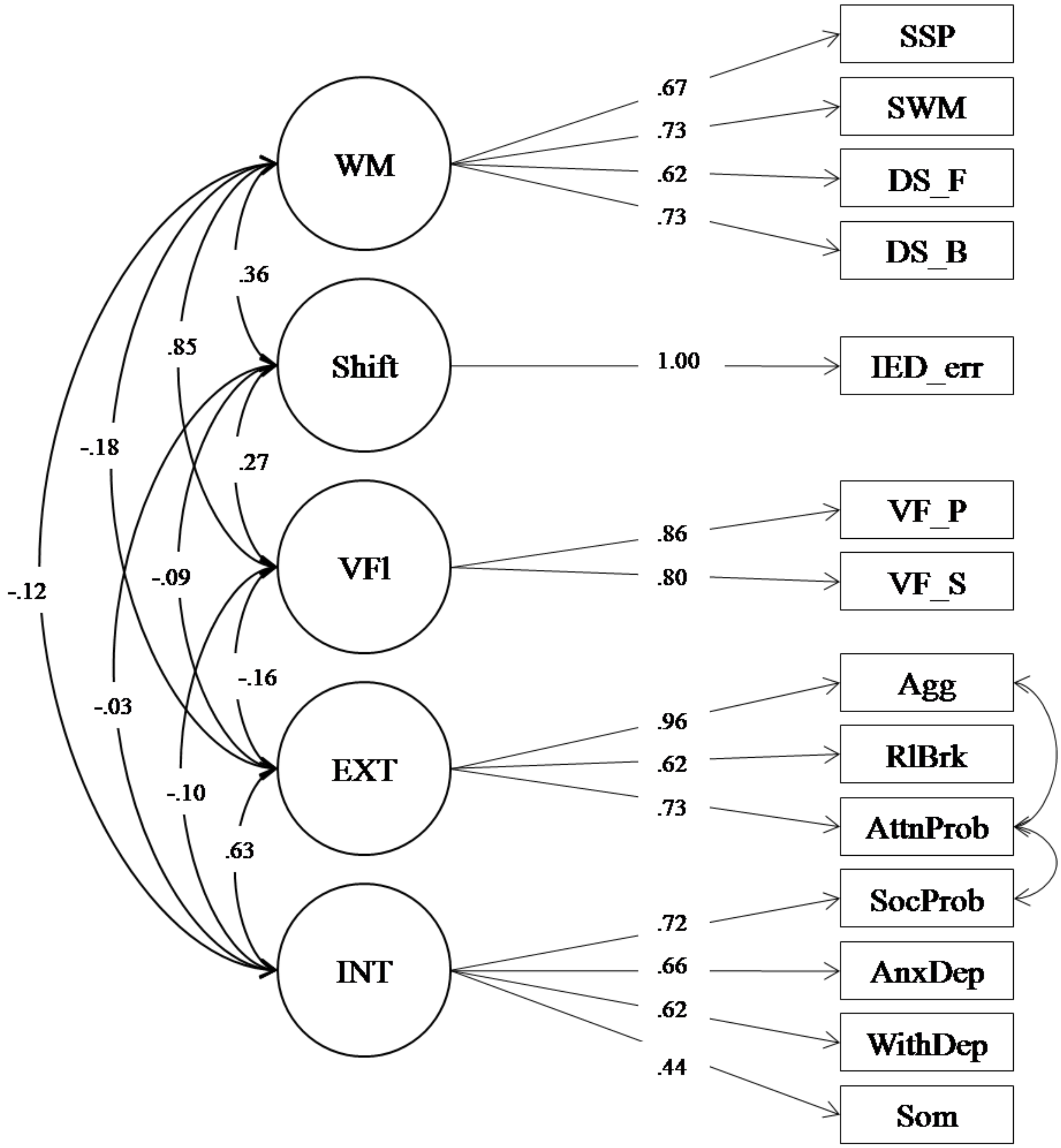

Figure 7. Confirmatory factor analysis of latent EF and psychosocial functioning constructs. Values depicted are completely standardized factor loadings. Freed residual estimates and latent factor variances (fixed at 1.0) were omitted for ease of presentation.

Measurement model with age. The second model examined was similar to the previously discussed full-sample CFA, with the addition of a latent Age factor to account for age-related variation in latent factor structure. The resulting model exhibited a close fit to the data ($\chi^2_{(66)}$ = 100.68, $p < .01$; RMSEA = .039; NNFI = .983; CFI = .990; see Figure 8). All manifest EF indicators loaded significantly ($p < .001$) and positively on their respective latent factors. Significant positive loadings were also noted between all EF indicators and Age, indicating improvement in EF task performance across the age range examined. As depicted in Table 11, significant negative loadings were revealed between Age and aggressive behavior ($p < .001$), rule-breaking ($p < .001$), and social problems ($p < .05$), indicating a decrease in the observed frequency of these behavioral problems across childhood and adolescence. In contrast, a significant positive loading was found between Age and withdrawn/depressed symptoms ($p < .05$). This likely reflects increased rates of depressive symptoms during adolescence (e.g., Garber, 2007). Attention problems, anxious/depressed symptoms, and somatic complaints failed to load significantly on Age, suggesting relative stability of these indicators across the age range examined[5].

[5] Given the higher frequency of missing data for CBCL rule-breaking and withdrawn/depressed subscales, manifest correlations between these variables and age were examined using non-imputed data and pairwise deletion (*N* = 289-351) to verify these results. Findings revealed an identical pattern of correlations, suggesting that the results obtained were not unduly influenced by the imputation methods utilized.

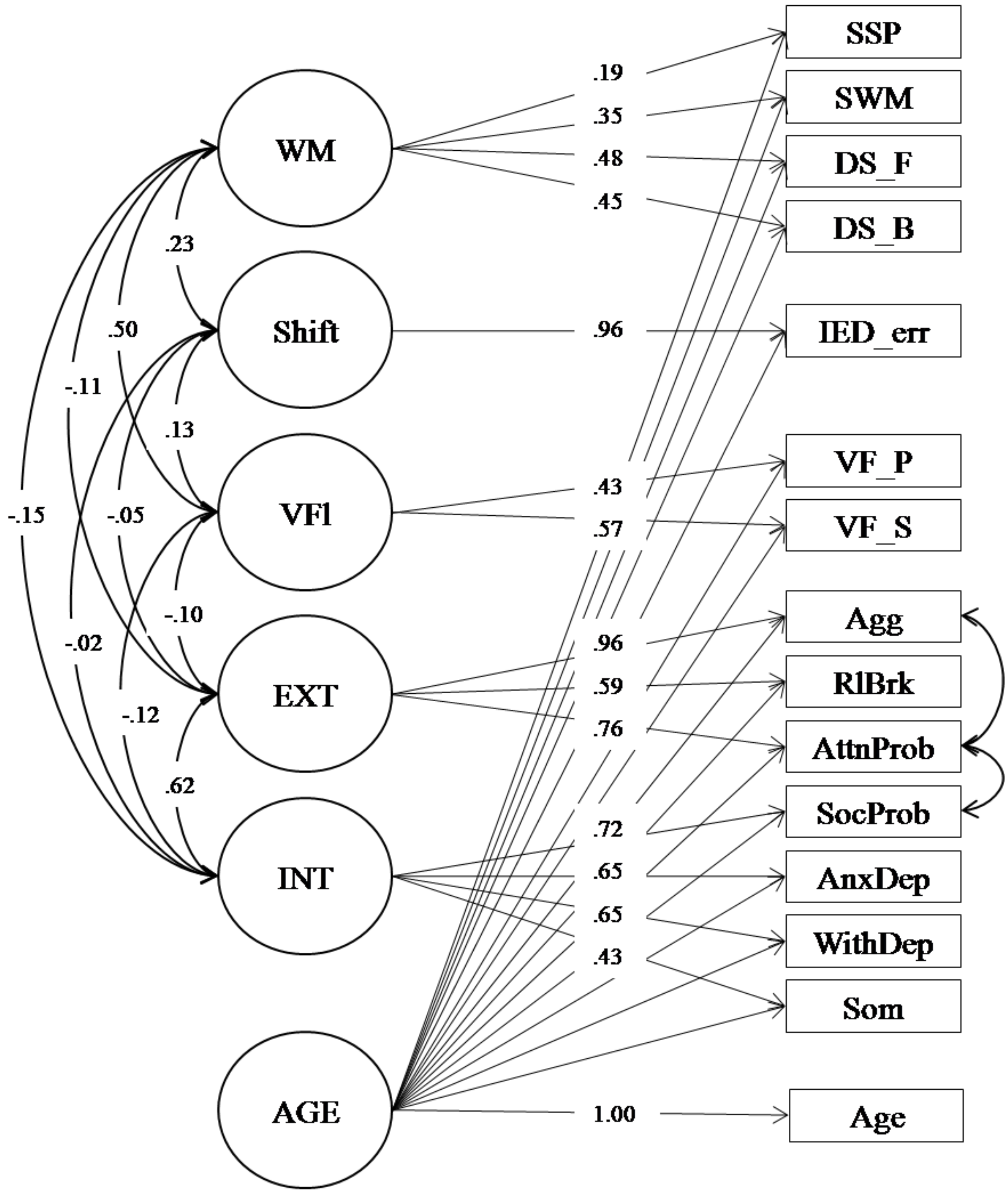

Figure 8. CFA solution for EF, psychosocial functioning, and age constructs. Values depicted are completely standardized factor loadings. Factor loadings on latent Age factor are depicted separately for ease of presentation (see Table 11).

Table 11.

Completely Standardized Factor Loadings of Manifest EF and Psychosocial Functioning Indicators on Latent Age Factor

Indicator	Factor loading	*p*-value
Spatial Span	.66	< .001
Spatial Working Memory	.63	< .001
Digit Span (Forward)	.46	< .001
Digit Span (Backward)	.60	< .001
Intradimensional/Extradimensional Shift (Errors)	.27	< .001
Verbal Fluency (Phonemic)	.71	< .001
Verbal Fluency (Semantic)	.62	< .001
Aggression	-.18	< .001
Rule Breaking	-.18	< .001
Attention Problems	-.02	ns
Social Problems	-.12	< .05
Anxious/Depressed	-.06	ns
Withdrawn/Depressed	.14	< .05
Somatic Complaints	.02	ns

The pattern of latent EF factor intercorrelations remained consistent, although the magnitude of association between Shifting and Verbal Fluency was reduced to just below significance in the current model (p = .06). Interestingly, differences in latent association between EF and psychosocial functioning factors were also noted. Although no associations fell below traditional levels of statistical significance, Working Memory demonstrated marginal/trend-level negative associations with Externalizing (p = .11) and Internalizing (p = .08). Marginal negative relations were also found between Verbal Fluency and Internalizing (p = .11) and Externalizing (p = .14).

Summary. While both full-sample measurement models fit the data closely, the inclusion of age altered the magnitude of correlations between latent factors, particularly for associations between Working Memory and Externalizing. Overall, findings suggested that developmental differences may exist in latent associations between EF and psychosocial functioning factors. Therefore, additional analyses were conducted to verify the nature of these putative developmental differences.

Objective 5: Investigate developmental differences in associations between latent EF factors and subclinical emotional/behavioral problems

Creation of developmental sub-groups. In order to facilitate analysis of developmental differences in the strength of associations linking EF and emotional/behavioral problems, it was necessary to sub-divide participants by age. However, given prohibitively small cell sizes for some ages, groups were created by collapsing across ages thought to reflect salient developmental periods [i.e., early elementary school (7-8 year olds; n = 91), elementary school (9-11 year olds; n = 100), junior high school/early adolescence (12-14 year olds; n = 80), and high school/adolescence (15-18 year olds; n = 81)]. Descriptive statistics for EF and psychosocial functioning variables separated by age group are provided in Table 12.

Table 12.

Descriptive Statistics for EF and Psychosocial Functioning Variables by Age Group

	Age group							
	7-8 yr olds		9-11 yr olds		12-14 yr olds		15-18 yr olds	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SSP	4.58	1.00	5.38	1.16	6.56	1.58	7.52	1.46
SWM (BTE)	48.37	19.78	39.70	17.88	23.69	16.30	15.16	12.81
DS (Forward)	7.13	1.50	8.23	1.85	9.71	2.02	9.56	2.04
DS (Backward)	4.27	1.41	4.89	1.63	6.26	1.89	7.16	1.82
IED (Errors)	26.88	16.11	26.84	11.90	20.35	13.76	18.62	12.28
VF (Phonemic)	12.73	6.74	20.72	8.46	27.05	8.14	33.11	9.39
VF (Semantic)	23.57	6.73	32.84	8.51	36.95	9.15	42.68	11.03
Aggression	3.09	2.94	2.49	2.74	2.56	2.78	1.86	2.23
Rule Breaking	1.41	1.37	0.98	1.29	0.73	0.94	0.84	1.59
Attn Problems	1.86	2.25	1.70	2.08	1.73	2.03	1.80	2.42
Soc Problems	1.09	1.29	1.19	1.49	0.89	1.30	0.75	1.41
Anx/Dep	1.85	1.90	1.51	1.62	1.78	1.84	1.49	1.91
With/Dep	0.77	1.05	0.63	0.98	0.91	1.24	1.20	1.60
Somatic	0.71	1.10	0.84	1.30	0.83	1.28	0.83	1.25
Age (years)	7.40	0.49	9.89	0.80	12.90	0.82	16.42	1.06

Note. SSP = Spatial Span, SWM (BTE) = Spatial Working Memory (Between Trial Errors), DS = Digit Span, IED = Intradimensional/Extradimensional Shift, VF = Verbal Fluency.

Measurement invariance. According to Brown (2006), "…it is not useful to compare groups on aspects of the latent factors (factor variances, factor covariances, latent means) without first ascertaining that the latent factors measure the same constructs in the same fashion in each group" (p. 291). Therefore, prior to testing for age differences in latent associations, measurement invariance was examined to determine comparability of constructs across developmental sub-groups. Brown (2006) suggested completion of the following increasingly restrictive steps in order to establish multi-group invariance:

(1) Test the CFA model separately in each group;

(2) conduct the simultaneous test of equal form (identical factor structure);

(3) test the equality of factor loadings;

(4) test the equality of indicator intercepts (p. 269).

First, baseline models were fit separately for each developmental subgroup. With the exception of three freed error parameters (Group 3: $\theta_{8,10}$, $\theta_{10,11}$; Group 4: $\theta_{10,11}$), model structure remained relatively consistent across groups. Moreover, model fit was adequate for each group with fit indices ranging from mediocre to close (Table 13).

Table 13.

Fit Indices for Full CFA Models by Age Group

Group	*n*	*df*	χ^2	AIC[a]	RMSEA[a]	NNFI[b]	CFI[b]
Early elementary school	91	68	91.54	165.54	.062	.895	.921
Elementary school	100	68	106.67**	180.67	.076	.859	.895
Early adolescence	80	67	89.30*	165.30	.065	.869	.904
Adolescence	81	67	75.28	151.29	.039	.977	.983

* $p < .05$, ** $p < .01$

[a] Lower values represent better model fit; RMSEA ≤ .05 indicates a close fit of the model.

[b] Values higher than .95 indicates a close fit of the model.

Note. AIC = Akaike Information Criterion, RMSEA = Root Mean Square Error of Approximation, NNFI = Non-Normed Fit Index/Tucker Lewis Index, CFI = Comparative Fit Index.

Second, a simultaneous multi-group CFA was conducted. The pattern of fixed and freed parameters was retained from the previous separate models. Global fit of the resulting model was acceptable ($\chi^2_{(362)} = 362.80$, $p < .001$; RMSEA = .063; NNFI = .910; CFI = .933); however, several differences were observed across groups with respect to the significance/salience of factor loadings. Specifically, among 12-14 year olds, spatial span failed to load significantly on Working Memory; and, among 15-18 year olds, spatial working memory fell just at (not below) the level of conventional significance (p = .05). In addition, the following factor loadings were found to be non-salient contributors to their respective model(s) as indicated by their completely standardized factor loadings of < .40: spatial span (Groups 1, 2, 3, 4), spatial working memory (Group 4), digit span-forward (Group 1), digit span-backward (Group 1), and somatic complaints (Groups 1, 3). Overall, these findings suggested that conditions for establishing measurement invariance (step 2) were not met.

The previous results notwithstanding, the equality of factor loadings (step 3) was tested to determine by more formal means if conditions of measurement invariance were satisfied. After imposing equality constraints on factor loadings across age-groups, the resultant model was compared to the baseline (unconstrained) model using a nested chi-square difference test, which was found to be highly significant ($\Delta\chi^2_{(27)} = 74.47$, $p < .001$). Thus, the hypothesis of measurement invariance was found to be unsustainable, thereby precluding formal statistical testing of age-group differences in latent associations between EF and psychosocial functioning[6].

Indeed, lack of invariance across groups suggested strongly that cross-group comparisons of latent associations would not be appropriate due to the presence of important disparities in the way latent factors were represented across groups (Horn & McArdle, 1992; Brown, 2006). Moreover, if formal statistical comparison were to have proceeded at this point, it would have been impossible to determine if significant results were due to substantive developmental differences in latent factor structure or decidedly

[6] An attempt was also made to determine if partial measurement invariance, as discussed by Byrne, Shavelson, & Muthen (1989), was achievable in the present sample. According to these authors, cross-group comparisons remain feasible if at least some of the indicators of each latent construct are invariant. Therefore, a series of CFAs were conducted in which factor loadings were systematically freed and resulting chi-square values were tested against the unconstrained model to determine if the offending parameters could be identified and isolated. Of particular interest was whether or not freeing the factors identified as non-significant/non-salient resulted in invariance. Unfortunately, all chi-square difference tests were significant, suggesting that the hypothesis of partial measurement invariance was not supported.

less meaningful differences (at least for the purposes of the current study) in the measurement of a given factor or factors.

In sum, testing of measurement invariance across developmental sub-groups revealed that the hypothesis of an invariant pattern of factor loadings was not supported in the current sample. Therefore, the following descriptions of latent factor structure and inter-construct associations within sub-groups are provided not as formal statistical tests of developmental differences in relations between EF and psychosocial functioning, but rather as qualitative accounts that may provide useful guidance to future investigators interested in addressing similar research questions.

Descriptions of latent factor models within developmental sub-groups

Group 1: Early elementary school

Among early elementary school children ranging in age from 7 to 8 years, significant positive associations were observed between Working Memory and both Shifting ($p < .05$) and Verbal Fluency ($p < .001$) latent EF constructs; however, Shifting and Verbal Fluency were not significantly interrelated. Latent Externalizing and Internalizing factors were also significantly positively correlated ($p < .001$). With respect to interrelations between EF and psychosocial functioning constructs, no statistically significant or trend-level associations were detected.

Group 2: Elementary school

Among elementary school children ranging in age from 9 to 11 years, significant positive associations were observed between Working Memory and both Shifting ($p < .05$) and Verbal Fluency ($p < .001$) latent EF constructs; however, Shifting and Verbal

Fluency were not significantly interrelated. Latent Externalizing and Internalizing factors were also significantly positively correlated ($p < .001$). With respect to correlations between EF and psychosocial functioning constructs, Working Memory was significantly negatively associated with Externalizing problems ($p < .05$). No other statistically significant or trend-level associations were detected.

Group 3: Early adolescence

Among early adolescents ranging in age from 12 to 14 years, no statistically significant correlations were observed among latent EF constructs; however, Working Memory did exhibit a trend-level positive association with Verbal Fluency ($p = .09$). Latent Externalizing and Internalizing factors were significantly positively correlated ($p < .001$). No statistically significant associations were found between latent EF and psychosocial functioning constructs; however, trend-level/marginal negative correlations were observed between Shifting and both Internalizing ($p = .07$) and Externalizing ($p = .11$) problems.

Group 4: Adolescence

Among adolescents ranging in age from 15 to 18 years, significant positive associations were observed among all three latent EF factors. Specifically, Working Memory was correlated significantly with Shifting ($p < .05$) and Verbal Fluency ($p < .001$); Shifting and Verbal Fluency were also significantly interrelated ($p < .05$). Latent Externalizing and Internalizing factors were significantly positively correlated ($p < .001$). With respect to correlations between EF and psychosocial functioning constructs, no statistically significant associations were found; however, trend-level/marginal negative correlations were observed between Working Memory and Internalizing (*p* = .06), as well as between Verbal Fluency and Internalizing problems (*p* = .12). Interestingly, an unexpected trend-level positive association between Shifting and Externalizing problems was also detected (*p* = .10).

Summary and Integration

Looking across age groups, several qualitative differences in latent factor structure and inter-construct associations were observed. First, regarding interrelations among latent EF constructs, it was not until adolescence (Group 4) that significant associations among all three factors were observed. Early elementary (7-8 year olds) and elementary school (9-11 year olds) age groups exhibited identical EF factor structure with significant positive relations between Working Memory and both Shifting and Verbal Fluency. Working Memory and Verbal Fluency were also positively interrelated in Group 3, albeit at a trend-level. In contrast, Shifting and Verbal Fluency constructs were not significantly correlated in early elementary, elementary, or early adolescent groups.

Second, regarding interrelations between latent EF and subclinical emotional/behavioral problems factors, results failed to reveal a consistent pattern across age groups. Nonetheless, there was at least some evidence that EF becomes increasingly relevant to psychosocial functioning across childhood and adolescence, particularly with respect to Internalizing difficulties. More specifically, whereas no significant or trend-level associations were observed within the youngest age group, Working Memory was significantly inversely related to Externalizing behavior problems among elementary school-age children (Group 2). No statistically significant correlations were found within early adolescent or adolescent groups (Groups 3 and 4); however, several trend-level/marginal negative associations were observed. Most notably, Shifting was negatively related to both Externalizing and Internalizing problems among early adolescents, and both Working Memory and Verbal Fluency were negatively associated with Internalizing among adolescents. In addition, an unexpected positive trend-level correlation was also noted between Shifting and Externalizing within the oldest age group. Of course, as previously discussed, these results must be interpreted with extreme caution given the increased likelihood that observed differences may reflect measurement discrepancies across age groups rather than substantive developmental changes in latent factor structure and organization.

CHAPTER 5

Discussion

The principal goals of the present study were to determine empirically the structure and organization of three executive function factors – Working Memory, Shifting, and Verbal Fluency – and to examine concurrent associations between EF and subclinical internalizing and externalizing behavior problems. Additionally, developmental differences in associations between EF and psychosocial functioning were investigated by comparing latent factor organization across age-based sub-groups. Data were collected from a large, nationally-representative sample of children and adolescents ranging in age from 7 to 18 years, and analyzed at the level of latent constructs rather than observed (i.e., manifest) variables. As such, the negative ramifications associated with task impurity were managed by extracting shared variance between and among theoretically-related variables, as well as by statistically controlling for non-executive factors (i.e., crystallized verbal intelligence and processing speed).

Structure and organization of executive function

First, the latent factor structure of Working Memory, Shifting, and Verbal Fluency was ascertained by conducting a series of confirmatory factor analyses. Initial examination of individual factor loadings revealed that two of nine manifest EF variables failed to demonstrate salient associations with their respective Working Memory and Shifting latent factors. Consequently, these indicators were removed from subsequent analyses. Notably, the two variables that did not contribute substantively to the model were both subscales from the Behavior Rating Inventory of Executive Function (BRIEF;

Gioia et al., 2000), a parent-report measure of purported everyday executive function abilities that recently has been shown to bear little relation to performance-based measures of EF (McAuley, Chen, Goos, Schachar, & Crosbie, 2010). Ultimately, CFA results indicated that a three-factor, fully intercorrelated model provided the best fit to the data. Thus, Working Memory, Shifting, and Verbal Fluency were identified as distinct, yet related latent EF constructs. The inclusion of Verbal Fluency as a distinct latent EF factor had not been attempted prior to the current study, and thus represents an important addition to the literature. Additionally, the finding that Working Memory and Shifting were distinguishable and correlated latent constructs is consistent with several previous reports (Miyake et al., 2000; Lehto et al., 2003; Huizinga et al., 2006; van der Sluis et al., 2007).

Next, having determined that a three-factor model best characterized the available data, additional CFAs were conducted to assess the impact of non-executive control variables – crystallized verbal intelligence and processing speed – on the latent factor structure of EF. Both control factors accounted for significant variance in all EF measures. Nonetheless, indicators also continued to load significantly on their respective latent EF factors, suggesting that non-executive skills could not account entirely for performance on EF tasks.

Regarding inter-construct associations, the inclusion of control factors differentially affected latent factor structure. Dealing first with the verbal abilities model, results revealed a significant positive relation between Working Memory and Verbal Fluency; however, the association between Working Memory and Shifting was no longer significant. These findings were consistent with van der Sluis et al. (2007), who also documented that Updating (i.e., Working Memory) and Shifting were only linked via non-executive variance. Interestingly, Verbal Fluency and Shifting evidenced a significant negative relation in the present study. Although somewhat counterintuitive at first, this finding may be explained by considering the nature of the shifting and verbal fluency tasks utilized. Specifically, the latent Shifting factor was constructed from errors registered on the CANTAB Intradimensional/Extradimensional Shift task (reverse-coded), which is primarily non-verbal in nature. Although participants may have enlisted an independently-generated verbal strategy to assist them while completing this task – perhaps accounting for the significant loading on the verbal intelligence control factor – the remaining variance still likely consisted largely of shifting errors. Verbal fluency tasks, on the other hand, call for speeded verbal output, freedom from repetition, and adherence to a given lexical or semantic category. By statistically extracting variance associated with verbal intellectual functioning, the remaining Verbal Fluency variance was likely comprised of a combination of mental speed and working memory-related features. It seems plausible, therefore, that in the context of a model controlling for verbal abilities, latent Verbal Fluency and Shifting factors may be negatively associated given that increased speed (i.e., fluency) may also increase one's likelihood of committing errors.

In the model accounting for processing speed, Working Memory remained significantly positively associated with Verbal Fluency; however, Shifting was not related to either Working Memory or Verbal Fluency. These findings suggest that the speed with which one is able to process information underlies associations between his or her cognitive shifting ability and other executive skills. Furthermore, the results of these control factor models call into question the findings from previous studies that failed to account for non-executive task demands. Indeed, by comparing controlled and uncontrolled models in the current study, it is clear that inter-construct associations would have been overestimated if variance related to basic verbal skills/information processing speed had not been taken into consideration. Even latent correlations between Working Memory and Verbal Fluency, which remained significant in all models examined, were reduced notably with the inclusion of control variables (i.e., from .85 in the uncontrolled model to .26 and .69 in verbal intelligence and processing speed models, respectively). Thus, consideration of non-executive influences shed important light on the conceptualization of EF structure and organization in the present study, and further verified the assertion that task impurity is managed most effectively within a latent variable framework capable of partialling executive and non-executive variance components.

These results should also be considered more broadly, in terms of their implications for understanding the unity and diversity of executive functions. Similar to several previous reports (Miyake et al., 2000; Lehto et al., 2003; Huizinga et al., 2006; van der Sluis et al., 2007), the present study documented evidence of both shared and distinct features among the EF factors examined. Although verbal abilities and processing speed each accounted for significant commonality across constructs, these control variables were at best partial contributors to the unity of the executive domains assessed. Additional research is needed to explore other potential sources of commonality.

In addition, though the current findings indicate clearly that executive skills cannot be understood as constituting a single entity, they by no means imply that the three factors investigated represent an exhaustive list of relevant EFs. The most notable absence was inhibitory control, although other executive function domains such as decision-making and planning may also prove important in charting the landscape of EF. Ideally, a comprehensive research battery of executive tasks would include multiple putative indicators of both basic and more complex executive functions. In the meantime, and at the very least, it seems reasonable to assert, as Miyake and his colleagues (2000) did, that with respect to questions of "unity versus diversity of executive functions…a simple dichotomy will not suffice, and both aspects must be taken into account" (p. 90).

EF and associations with psychosocial functioning

The second goal of this study was to examine concurrent associations between EF and subclinical psychosocial difficulties. The first step toward this objective was achieved by modeling the latent factor structure of Internalizing and Externalizing behavior problems. A correlated two-factor model with two freed error parameters best fit the data and was maintained in subsequent analyses. Two CFAs were then conducted consisting of three latent EF factors (Working Memory, Shifting, and Verbal Fluency) and two psychosocial functioning factors (Internalizing and Externalizing), with and without age, and found to provide a close fit to the data. Inter-construct relations revealed small but significant negative correlations between Externalizing and both Working

Memory (-.18) and Verbal Fluency factors (-.16). In addition, marginal/trend-level negative associations were noted between Internalizing and both Working Memory (-.12) and Verbal Fluency (-.10), as well as between Externalizing and Shifting (-.09). The addition of age to the model altered the magnitude of latent associations between EF and psychosocial functioning factors; however, the overall pattern of interrelations remained relatively consistent. Specifically, trend-level relations remained between Externalizing and both Working Memory (-.11) and Verbal Fluency (-.10), as well as between Internalizing and these EFs (-.11 with Working Memory; -.15 with Verbal Fluency). Shifting was not associated with either psychosocial functioning factor.

Overall, these results suggest that individual differences in certain domains of executive function track meaningfully and in expected directions with subclinical emotional and behavioral problems. Externalizing difficulties, in particular, were more reliably predicted by latent Working Memory and Verbal Fluency factors, although these domains of functioning did account for marginally significant portions of variance in Internalizing problems, as well. Séguin (2004; Séguin & Zelazo, 2005) posited that the role of working memory in regulating behavioral problems may be linked to social information processing and problem solving. Given the present findings, this seems to be a reasonable hypothesis. For example, a child who is better able to mentally represent and simultaneously consider multiple response options, as well as their respective consequences, may engage in more effective social problem-solving when confronted with hostile or threatening circumstances. Working memory may also help facilitate a more accurate appraisal of the full array of positive and negative outcomes potentially accompanying more premeditated/instrumental aspects of Externalizing (e.g., theft, truancy), which may serve to down-regulate antisocial tendencies.

Likewise, the trend-level relation between Working Memory and Internalizing may also be related to several factors. Difficulties with attention and concentration frequently co-exist with pediatric mood disorders (Emerson et al., 2005; Forbes et al., 2007; Halari et al., 2009; Kyte et al., 2005). Insofar as basic attention faculties are required to complete all tasks of working memory (e.g., Fernandez-Duque & Johnson, 2002), it makes sense that children experiencing even relatively subtle difficulties with attention might also be expected to perform more poorly on working memory tests than their peers. Theoretically, these working memory impairments may, in turn, feed into further internalizing problems if, for example, a child who is less able to consider multiple interpretations of a situation is hindered in his or her ability to divert initial negative thoughts toward alternative neutral or positive appraisals. In this case, diminished working memory abilities may promote rumination and lessen that individual’s capacity to cognitively reframe experiences that otherwise seem to conform to his or her negative interpretation biases.

Links between verbal abilities and conduct problems have also been recognized for many years (Moffitt, 1993b); yet, with a few notable exceptions (e.g., Stanford et al., 1997; Nigg et al., 1999), most previous studies have focused on crystallized verbal abilities while overlooking more executive aspects of language functioning such as verbal fluency. Thus, the present investigation contributes to the existing literature by documenting that children and adolescents with more well-developed verbal fluency skills are less likely to engage in parent-reported problem behaviors. The nature of this association remains open to interpretation; however, one compelling argument is that individuals who can more easily assert themselves verbally are better equipped to manage troublesome interpersonal situations with words rather than physical prowess (e.g., Moffitt, 1993b). Conversely, the inability to express one's thoughts effectively, whether real or perceived, is likely to fuel feelings of frustration, which may ultimately find expression non-verbally as emotional and/or behavioral dysregulation. Of course, as Nigg and colleagues (1999) pointed out, this argument may hold for both internalizing and externalizing problems. Indeed, one could just as easily envision a frustrated and emotionally dysregulated child or adolescent turning his or her feelings inward and subsequently finding it difficult to disengage from ruminative, depressogenic thought patterns. This may explain the marginally significant association between Verbal Fluency and Internalizing in the current study. Further investigation is needed to clarify the nature of verbal fluency as a protective influence against psychosocial maladjustment.

Developmental differences in associations between EF and psychosocial functioning

The final aim of this study was to explore developmental differences in associations between executive functions and subclinical emotional and behavioral problems. Participants were separated into four age-based sub-groups (i.e., early elementary school [7-8 year olds], elementary school [9-11 year olds], junior high school/early adolescence [12-14 year olds], and high school/adolescence [15-18 year olds] to facilitate comparisons across salient developmental periods.

Separate CFA models were then examined and the proposed factor structure was found to provide a generally adequate fit across age groups, with no significant cross-loadings among EF variables. Thus, a simultaneous multi-group CFA was conducted wherein the same pattern of fixed and freed parameters was retained from previous analyses. The results of this CFA provided the first evidence of non-invariance across groups by identifying the following as non-significant and/or non-salient indicator variables: spatial span (Groups 1, 2, 3, 4), spatial working memory (Group 4), digit span-forward (Group 1), digit span-backward (Group 1), and somatic complaints (Groups 1, 3). Nonetheless, an additional multi-group CFA in which factor loadings were equated across age groups was conducted in order to more objectively assess measurement invariance. Ultimately, the results of a nested chi-square difference test proved highly significant ($\Delta\chi^2_{(27)} = 74.47$, $p < .001$), thereby verifying that the hypothesis of measurement invariance was, in fact, untenable.

These results indicated that formal statistical comparison of latent associations across groups would have been inappropriate due to the inability of such comparisons to distinguish substantive developmental differences from psychometric discrepancies. Indeed, as outlined by Horn and McArdle (1992),

> The general question of invariance of measurement is one of whether or not, under different conditions of observing and studying phenomena, measurements yield measures of the same attributes. If there is no evidence indicating presence or absence of measurement invariance—the usual case—or there is evidence that such invariance does not obtain, then the basis for drawing scientific inference is

> severely lacking: findings of differences between individuals and groups cannot be unambiguously interpreted. (p. 117)

One potential explanation for the lack of invariance was that the non-significant/non-salient indicators previously identified made it impossible to equate factor loadings across groups without significantly worsening model fit. However, even removal of the equality constraints previously imposed on these variables failed to establish cross-group invariance. Consequently, the nature of the observed lack of measurement invariance remains unclear.

Qualitatively, there appeared to be several differences across groups in terms of both latent factor structure and associations between EF and psychosocial functioning; however, it warrants repeating that these results are at best preliminary and must be interpreted with extreme caution.

Regarding differences in the latent factor structure of EF, significant correlations among Working Memory, Shifting, and Verbal Fluency were not apparent until adolescence, although separate associations between Working Memory and both Shifting and Verbal Fluency were noted in early elementary and elementary school age-groups as well. Early adolescents exhibited only a trend-level positive relation between Working Memory and Verbal Fluency ($p = .09$); otherwise, there were no significant associations between latent EF factors. Given that interrelations among EF factors were securely in place by adolescence, perhaps the earlier disunity suggests that 12-14 years of age represents a transitional period during which EF organization is in a state of relative flux before undergoing further integration during later adolescence and young-adulthood.

Working Memory development, for example, is known to follow a protracted course with continued refinement well into young-adulthood (e.g., Conklin et al., 2007; Huizinga et al., 2006). Similar to the method adopted in the current study to examine the role of non-executive factors in EF organization, future investigations should consider partitioning Working Memory variance components from other EF constructs in order to examine their impact on the latent factor structure of executive functions.

Finally, with respect to links between latent EF and Externalizing/Internalizing constructs, again several qualitative differences were documented. The only statistically significant correlation was found between Working Memory and Externalizing problems within the 9-11-year age group; however, several marginal/trend-level associations were noted among early adolescents and adolescents. In particular, among 12-14-year olds, individuals who were more effective in set shifting tended also exhibit fewer behavioral (-.18, $p = .11$) and emotional problems (-.23, $p = .07$) than their peers. Furthermore, among 15-18-year olds, more well-developed Working Memory and Verbal Fluency abilities were associated with decreased parent-reported Internalizing problems (-.27, $p = .06$ and -.22, $p = .12$ for Working Memory and Verbal Fluency, respectively). Unexpectedly, Shifting was positively related to Externalizing (.18, $p = .10$) within the 15-18-year group, as well, indicating that better performance on a set shifting task was related to increased rates of behavior problems. The nature of this correlation is unclear; however, it may have been informative to disaggregate aggressive and rule-breaking Externalizing subscales in order to determine if this finding was similar to Barker et al. (2007), who documented inverse relations between EF and aggressive (but not non-aggressive) behavioral problems. Indeed, the use of composite psychosocial functioning indicators was a limitation of the current study and may have masked important within-domain differences.

CHAPTER 6

Limitations, Implications, and Future Directions

The current study offered a latent variable investigation of the structure and organization of executive function, as well as associations with psychosocial functioning, in the most-representative sample of healthy, United States children and adolescents to date. Nonetheless, as is true with all research projects, this investigation was limited in several respects including the lack of inhibitory control measures, the use of a single-indicator Shifting factor, an exclusive focus on “cool” aspects of EF, and the use of heterogeneous psychosocial functioning composite factors. These important limitations will now be discussed, as well as relevant implications and directions for future research.

Limitations

First, the lack of performance-based measures of inhibitory control precluded examination of a latent inhibitory control factor. Despite mixed evidence for the existence of a distinct inhibition latent factor in prior investigations of children and adolescents (Huizinga et al., 2006; van der Sluis et al., 2007), adult studies generally recognize inhibitory control as one of three fundamental executive functions, along with working memory and shifting (Miyake et al., 2000). Moreover, inhibition has been described as crucial to understanding associations between self-regulation and psychosocial adaptation, particularly with respect to externalizing behavior problems (e.g., Barkley, 1997). Therefore, the omission of behavioral measures of inhibitory control represents a major limitation of the current study.

Second, due to their lack of substantive value to the hypothesized model, two theoretically meaningful manifest indicators were omitted from this study's primary analyses. As one of these variables represented half of the available Shifting indicators, this unfortunately meant that only a single indicator remained with which to identify the Shifting factor (i.e., CANTAB Intradimensional/Extradimensional Shift – Errors). Since 1) this indicator cannot realistically be considered "perfectly reliable (i.e., entirely free of measurement error)" (Brown, 2006, p. 139) and 2) the lack of multiple indicators made it impossible to extract common variance in constructing the latent factor, it is likely that the Shifting factor included in this study is not sufficiently representative of Shifting as it has been more generally defined in the literature.

Third, despite growing recognition of the distinction between "hot" and "cool" aspects of executive function, the tasks employed in the current study focused exclusively on decontextualized, "cool" EFs. While it is true that some have adopted measures of more motivationally-salient decision-making that involve both ventral-medial/orbitofrontal and dorsolateral prefrontal cortex (e.g., Iowa Gambling Task; Bechara et al., 1994), no such tasks were included in the current study. This represents a potentially informative avenue for future research, especially considering that there have been no such latent variable investigations to date.

Finally, psychosocial functioning was gauged exclusively via parent-report questionnaires and examined as composite indices of broadly defined Externalizing and Internalizing problems. Future research should include additional measures of emotional and behavioral problems from other sources including participants, teachers, peer-reports, and naturalistic observations (for younger children). Moreover, the use of aggregate measures of emotional/behavioral problems risks masking important differences within a given category. Most notably, the current study collapsed across violent and non-violent forms of Externalizing behavior problems, thus overlooking potentially meaningful differences in associations between EF and these distinct, yet often related behavior problems (e.g., Barker et al., 2007; Broidy et al., 2003). The current study also focused on children and adolescents whose emotional and behavioral problems fell below clinical cut-off points on the CBCL. Therefore, additional research is needed to validate the obtained findings among samples of children and adolescents experiencing clinically elevated psychosocial maladjustment.

Implications

Assessment of executive functions is routine in pediatric neuropsychological evaluation (Baron, 2004). Still, clinicians differ widely in their method of determining the integrity of various executive skills. The present study is in line with several previous investigations suggesting that EF cannot and should not be considered a unitary construct assessable via performance on any single test. Rather, executive functions exist as a constellation of interconnected yet distinguishable cognitive self-regulatory mechanisms, each potentially meaningful for understanding how a child navigates his or her environment. Alas, this does not change the fact that clinicians are forced to operate within a system of time constraints and third-party reimbursement that imposes limits on how deeply a given cognitive domain can be explored. These limits are real, and they must be acknowledged. Clinicians should be explicit in interpreting the aspects of EF they assess, making certain to avoid over-generalizing performance on one EF measure as evidence of the integrity or impairment of executive functioning more broadly. Clinicians should also, within the context of the specific referral question or questions, administer a battery of EF tasks that sample several executive skills including working memory, set shifting, problem solving, inhibitory control, and verbal fluency. Moreover, the results obtained from these measures must be interpreted within the context of the child's larger profile of neurocognitive performance, as well as his or her developmental history and motivation toward testing, and psychometric limitations of the instruments utilized (Bernstein, 2000).

With respect to the observed associations between EF and psychosocial functioning, the concurrent nature of the present study makes it impossible to determine the direction of these relations. In other words, it is unclear whether EF difficulties increase risk for emotional/behavioral problems or if emotional/behavioral problems increase risk for EF difficulties. Perhaps the most likely scenario is one in which these factors exert complex, bidirectional influences that are not as easily depicted in cause-effect studies. These important questions notwithstanding, the fact that executive functions appear to be related in some way to psychosocial adjustment, even at subclinical levels, suggests that prevention and intervention efforts may be improved by attempts to bolster cognitive self-regulatory abilities (Paschall & Fishbein, 2002; Riggs et al., 2006).

Yet another implication of this study pertains to the use of latent variable modeling in elucidating brain-behavior relations. One of the most significant drawbacks of exploratory factor analysis is the likelihood that factors extracted from theoretically dissimilar variables will ultimately prove limited in their capacity to identify mediating neural systems (e.g., Zelazo et al., 1997; 2003). On the other hand, confirmatory factor analytic methods, which combine variance shared across hypothetically related manifest indicators while minimizing measurement error, may offer a useful alternative (e.g., Miyake et al., 2000). It is unlikely that the latent factors identified would map cleanly onto independent/dissociable neural systems. Still, latent variable analysis may prove informative in helping to delineate the structure and organization of EF from a multi-level perspective. For example, within the context of a functional magnetic resonance imaging (fMRI) paradigm, it may be possible to administer a battery of EF tasks (e.g., digit span, spatial working memory) and subsequently examine regions of interest (e.g., [left/right] dorsolateral prefrontal cortex, orbitofrontal cortex, anterior cingulate cortex) as manifest indicators of a putative "latent activation network" recruited to perform a given executive operation. Such a design would certainly offer a novel approach for interpreting neuroimaging data, perhaps shedding new light on the neural processes underlying higher-level cognitive functions. Of course, as others have noted (Miyake et al., 2000), such a study would also be very costly, both in terms of the funding and time necessary to organize, recruit, and run a sample of adequate size to permit latent variable statistical analyses. However, multi-center investigations like the NIH MRI Study of Normal Brain Development provide a model of the kind of collaborative efforts required to overcome such limitations.

Future Directions

This study also highlights several directions for future research. As discussed, the concurrent nature of this investigation limits analyses to correlation-based methods that cannot be used to infer causality. However, as an ongoing longitudinal project, the NIH MRI Study of Normal Brain Development holds promise for shedding some much-needed light on these important research questions. For example, although children were screened for clinically significant problem behaviors prior to their inclusion in this study, rates of problem behaviors follow normative developmental courses and thus, at later assessment points, participants may demonstrate changes in their psychosocial adaptation. It would be interesting to examine these changes within the context of previous development to determine potential risk-factors for onset of psychopathology.

Future studies should also be designed to explicitly test more putative contributors to the unity and diversity of executive functions. Currently, working memory, inhibitory control, and problem-solving accounts represent three plausible theoretical frameworks against which to address these questions. By collecting multiple indicators of these constructs, as well as measures of other theoretically related executive and non-executive factors, it may be possible to examine competing models of EF structure and organization, and in so doing, to determine empirically which of these conceptualizations best characterizes the nature of childhood and adolescent executive functioning.

REFERENCES

Achenbach, T. M. (2001). *Manual for the ASEBA School-Age Forms and Profiles (Child Behavior Checklist for Ages 6 – 18).* Burlington, VT: University of Vermont.

Allman, J., Hakeem, A., Erwin, J. M., Nimchinsky, E., & Hof, P. (2001). Anterior cingulate cortex: The evolution of an interface between emotion and cognition. *Annals of the New York Academy of Sciences, 935*, 107-117,

Baddeley, A. D. (1986). *Working memory.* New York: Oxford University Press.

Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Science, 4*, 417-423.

Baddeley, A.D., & Hitch, G. (1974). Working memory. In G.H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.

Baldo, J. V., Shimamura, A. P., Delis, D. C., Kramer, J., & Kaplan, E. (2001). Verbal and design fluency in patients with frontal lobe lesions. *Journal of the International Neuropsychological Society, 7,* 586-596.

Barker, E. D., Séguin, J. R., White, H. R., Bates, M. E., Lacourse, E., Carbonneau, R., et al. (2007). Developmental trajectories of male physical violence and theft: Relations to neurocognitive performance. *Archives of General Psychiatry, 64,* 592-599.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Baron, I. S. (2004). *Neuropsychological evaluation of the child.* New York: Oxford University Press.

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.

Bernstein, J. H. (2000). Developmental neuropsychological assessment. In K. O. Yeates, M. D. Ris, & H. G. Taylor (Eds.), *Pediatric neuropsychology: Research, theory, and practice* (pp. 405-438). New York: Guilford Press.

Blumer, D., & Benson, D. F. (1975). Personality changes with frontal and temporal lobe lesions. In D. F. Benson & D. Blumer (Eds.), *Psychiatric aspects of neurologic disease* (pp. 151-169). New York: Grune & Stratton.

Braver, T. S., Cohen, J. D., Nystrom, L. E., Jonides, J., Smith, E. E., & Noll, D. C. (1997). A parametric study of prefrontal cortex involvement in human working memory. *Neuroimage, 5,* 49-62.

Broca, P. (1865). Sur la faculte du langage articule. *Bulletin of Sociological Anthropology, Paris, 6*, 337-393.

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

Broidy, L. M., Nagin, D. S., Trembley, R. E., Bates, J. E., Brame, B., Dodge, K. A., et al. (2003). Developmental trajectories of childhood disruptive behaviors and adolescent delinquency: A six-site, cross-national study. *Developmental Psychology, 39*, 222-245.

Brown, T. A. (2006). *Confirmatory factor analysis for applied research.* New York: The Guilford Press.

Byrne, B. M., Shavelson, R. J., & Muthen, B. (1989). Testing for the equivalence of factor covariance and mean structures: The issue of partial measurement invariance. *Psychological Bulletin*, *105,* 456-466.

Calkins, S. D., & Marcovitch, S. (2010). Emotion regulation and executive functioning in early development: Integrated mechanisms of control supporting adaptive functioning. In S. D. Calkins & M. A. Bell (Eds.), *Child development at the intersection of emotion and cognition.* Washington DC: American Psychological Association.

Canavan, A., Janota, I., & Schurr, P. H. (1985). Luria's frontal lobe syndrome: Psychological and anatomical considerations. *Journal of Neurology, Neurosurgery, and Psychiatry, 48,* 1049-1053.

Case, R. (1992). The role of the frontal lobes in the regulation of cognitive behavior. *Brain and Cognition, 20,* 51-73.

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.

CeNeS. (1998). *Cambridge Neuropsychological Test Automated Battery* (Version 2.35). Cambridge, UK: CeNeS Cognition.

Ciairano, S., Visu-Petra, L., & Settanni, M. (2007). Executive inhibitory control and cooperative behavior during early school years: A follow-up study. *Journal of Abnormal Child Psychology, 35*, 335-345.

Cicchetti, D., & Rogosch, F. A. (1996). Equifinality and multifinality in developmental psychopathology. *Development and Psychopathology, 8*, 597-600.

Clark, J. M. (1996). Contributions of inhibitory mechanisms to unified theory in neuroscience and psychology. *Brain and Cognition*, *30*, 127-152.

Clark, C., Prior, M., & Kinsella, G. (2002). The relationship between executive function abilities, adaptive behaviour, and academic achievement in children with externalizing behaviour problems. *Journal of Child Psychology and Psychiatry, 43*, 785-796.

Cole, P. M., Usher, B. A., & Cargo, A. P. (1993). Cognitive risk and its associations with risk for disruptive behavior disorder in preschoolers. *Journal of Clinical Child Psychology, 22*, 154-164.

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.

Crick, N. R. (1997). Engagement in gender normative versus nonnormative forms of aggression: Links to social-psychological adjustment. *Developmental Psychology, 33*, 610-617.

Crick, N. R., & Dodge, K. A. (1996). Social information-processing mechanisms in reactive and proactive aggression. *Child Development, 67*, 993-1002.

Crick, N. R., & Grotpeter, J. K. (1995). Relational aggression, gender, and social-psychological adjustment. *Child Development*, *66,* 710-722.

Crick, N. R., & Zahn-Waxler, C. (2003). The development of psychopathology in females and males: Current progress and future challenges. *Development and Psychopathology, 15*, 719-742.

Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin*, *52*, 281-302.

Damasio, A. R. (1994). *Descartes' error.* New York: Putnam.

Damasio, H., Grabowski, T., Frank, R., Galaburda, A. M., & Damasio, A. R. (1994). The return of Phineas Gage: Clues about the brain from the skull of a famous patient. *Science, 264*, 1102-1105.

Denckla, M. B. (1994). Measurement of executive function. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement issues* (pp. 263-277).

Dery, M., Toupin, J., Pauze, R., Mercier, H., & Fortin, L. (1999). Neuropsychological characteristics of adolescents with conduct disorder: Association with attention-deficit-hyperactivity and aggression. *Journal of Abnormal Child Psychology*, *27,* 225-236.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 16,* 279-281.

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's A-not-B task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research, 74,* 24-40.

Dias, R., Robbins, T. W. & Roberts, A. C. (1996). Dissociation in prefrontal cortex of affective and attentional shifting. *Nature, 380,* 69-72.

Duncan, J., Johnson, R., Swales, M., & Freer, C. (1997). Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology, 14,* 713-741.

Elliott, F. A. (1978). Neurological aspects of antisocial behavior. In W. H. Reid (Ed.), *The psychopath* (pp. 146-189). New York: Bruner/Mazel.

Emerson, C. S., Mollet, G. A., & Harrison, D. W. (2005). Anxious-depression in boys: An evaluation of executive functioning. *Archives of Clinical Neuropsychology, 20,* 539-546.

Evans, A. C. (2006). The NIH MRI study of normal brain development. *NeuroImage, 30,* 184-202.

Favre, T., Hughes, C., Emslie, G., Stavinoha, P., Kennard, B., & Carmody, T. (2009). Executive functioning in children and adolescents with major depressive disorder. *Child Neuropsychology, 15,* 85-98.

Fernandez-Duque, D., & Johnson, M. L. (2002). Cause and effect theories of attention: The role of conceptual metaphors. *Review of General Psychology, 6,* 153-165.

Fodor, J. A. (1983). *The modularity of mind.* MIT Press.

Forbes, E. E., Shaw, D. S., & Dahl, R. E. (2007). Alterations in reward-related decision making in boys with recent and future depression. *Biological Psychiatry, 61,* 633-639.

Garber, J. (2000). Development and depression. In A. Samaroff, M. Lewis, & S. Miller (Eds.), *Handbook of developmental psychopathology* (pp. 467-490) (2nd ed.). New York: Plenum.

Garber, J. (2007). Depression in youth: A developmental psychopathology perspective. In A. Masten & L.A. Sroufe (Eds.), *Multilevel dynamics in developmental psychopathology: Pathways to the future, Vol. 34* (pp. 181-242) New York: Erlbaum.

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

Giancola, P. R. (1995). Evidence for dorsolateral and orbital prefrontal cortical involvement in the expression of aggressive behavior. *Aggressive Behavior, 21*, 431-450.

Giancola, P. R., Martin, C. S., Tarter, R. E., Pelham, W. E., & Moss, H. B. (1996). Executive cognitive functioning and aggressive behavior in preadolescent boys at high risk for substance abuse/dependence. *Journal of Studies on Alcohol, 57,* 352-359.

Giancola, P. R., Mezzich, A. C., & Tarter, R. E. (1998a). Disruptive, delinquent and aggressive behavior in female adolescents with a psychoactive substance use disorder: Relation to executive cognitive functioning. *Journal of Studies on Alcohol, 59*, 560-567.

Giancola, P. R., Mezzich, A. C., & Tarter, R. E. (1998b). Executive cognitive functioning, temperament, and antisocial behavior in conduct-disordered adolescent females. *Journal of Abnormal Psychology, 107,* 629-641.

Giancola, P. R., Moss, H. B., Martin, C. S., Kirisci, L., & Tarter, R. E. (1996). Executive cognitive functioning predicts reactive aggression in boys at high risk for substance abuse: A prospective study. *Alcoholism: Clinical and Experimental Research, 20,* 740-744.

Giancola, P. R., & Zeichner, A. (1994). Neuropsychological performance on tests of frontal-lobe functioning and aggressive behavior in men. *Journal of Abnormal Psychology, 103*, 832-835.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Costellanos, F. X., Vaituzis, A. C., Fernandez, T., et al. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience, 2,* 861-863.

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

Golden, C. J. (1978). *Stroop Color and Word Test: A manual for clinical and experimental uses.* Chicago: Stoelting.

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-age child* (pp. 277-302). New York: Grune & Stratton.

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

Graham, J. W., Cumsille, P. E., & Elek-Fisk, E. (2003). Methods for handling missing data. In J. A. Schinka & W. F. Velicer (Eds.), *Handbook of psychology: Research methods in psychology, Vol. 2.* (pp. 87-114.) New York: Wiley.

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.

Halari, R., Simic, M., Pariante, C. M., Papadopoulos, A., Cleare, A., Brammer, M., et al. (2009). Reduced activation in lateral prefrontal cortex and anterior cingulate during attention and cognitive control functions in medication-naïve adolescents with depression compared to controls. *Journal of Child Psychology and Psychiatry, 50,* 307-316.

Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *Proceedings of the Massachusetts Medical Society, 2,* 327-346.

Hinshaw, S. P. (2002). Process, mechanism, and explanation related to externalizing behavior in developmental psychopathology. *Journal of Abnormal Child Psychology, 30,* 431-446.

Hoaken, P. N. S., Shaughnessy, V. K., & Pihl, R. O. (2003). Executive cognitive functioning and aggression: Is it an issue of impulsivity? *Aggressive Behavior, 29,* 15-30.

Hongwanishkul, D., Happaney, K. R., Lee, W. S. C., & Zelazo, P. D. (2005). Assessment of hot and cool executive function in young children: Age-related changes and individual differences. *Developmental Neuropsychology*, *28,* 617-644.

Horn, J. L., & McArdle, J. J. (1992). A practical and theoretical guide to measurement invariance in aging research. *Experimental Aging Research*, *18*, 117-144.

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling*, *6*, 1-55.

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.

Jasper, H. H. (1995). A historical perspective: The rise and fall of prefrontal lobotomy. In H. H. Jasper, R. Riggio, & P. S. Goldman-Rakic (Eds.), *Advances in neurology: Vol. 66. Epilepsy and the functional anatomy of the frontal lobe* (pp. 97-114). New York: Raven Press.

Joreskog, K., & Sorbom, D. (2007). *LISREL 8.80.* Scientific Software International, Inc.

Keenan, K., & Shaw, D. (1997). Developmental and social influences on young girls' early problem behavior. *Psychological Bulletin*, *121*, 95-113.

Kerr, A., & Zelazo, P. D. (2004). Development of “hot” executive function: The Children’s Gambling Task [Special Issue: Development of Orbitofrontal Function]. *Brain and Cognition*, *55*, 148-157.

Kimberg, D.Y., D'Esposito, M., & Farah, M.J. (1997). Cognitive functions in the prefrontal cortex – Working memory and executive control. *Current Directions in Psychological Science, 6,* 185-192.

Kimberg, D. Y., & Farah, M. J. (1993). A unified account of cognitive impairments following frontal lobe damage: The role of working memory in complex, organized behavior. *Journal of Experimental Psychology: General, 122,* 411-428.

Korkman, M., Kirk, U., & Kemp, S. (1998). *NEPSY: A Developmental Neuropsychological Assessment.* San Antonio, TX: Psychological Corporation.

Kusché, C. A., Cook, E. T., & Greenberg, M. T. (1993). Neuropsychological and cognitive functioning in children with anxiety, externalizing, and comorbid psychopathology. *Journal of Clinical Child Psychology, 22,* 172-195.

Kyte, Z. A., Goodyer, I. M., & Sahakian, B. J. (2005). Selected executive skills in adolescents with recent first episode major depression. *Journal of Child Psychology and Psychiatry, 46,* 995-1005.

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

Levin, H. S., Culhane, K. A., Hartman, J., Evankovich, K., Mattson, A., Harward, H., et al. (1991). Developmental changes in performance on tests of purported frontal lobe functioning. *Developmental Neuropsychology, 7,* 377-395.

Lilienfeld, S. O. (2003). Comorbidity between and within childhood externalizing and internalizing disorders: Reflections and directions. *Journal of Abnormal Child Psychology, 31*, 285-291.

Loehlin, J. C. (2004). *Latent variable models: An introduction to factor, path, and structural equation analysis (4th edition).* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Luciana, M. (2003). Practitioner review: Computerized assessment of neuropsychological function in children: Clinical and research applications of the Cambridge Neuropsychological Testing Automated Battery (CANTAB). *Journal of Child Psychology and Psychiatry, 44,* 649-663.

Luciana, M. (2006). Cognitive neuroscience and the prefrontal cortex: Normative development and vulnerability to psychopathology. In D. Cicchetti & D. Cohen (Eds.), *Developmental Psychopathology (2nd ed.): Developmental Neuroscience* (Vol. 3). New York: Wiley.

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.

Luciana, M., & Nelson, C. A. (1998). The functional emergence of prefrontally-guided working memory systems in four- to eight-year-old children. *Neuropsychologia, 36*, 273-293.

Luciana, M., & Nelson, C. A. (2002). Assessment of neuropsychological function through use of the Cambridge Neuropsychological Testing Automated Battery:

Performance in 4- to 12-year-old children. *Developmental Neuropsychology, 22,* 595-624.

Luria, A. R. (1961). *The role of speech in the regulation of normal and abnormal behavior.* New York: Liveright.

Luria, A. R., Pribram, K. H., & Homskaya, E. D. (1964). An experimental analysis of the behavioural disturbance produced by a left frontal arachnoidal endothelioma (meningioma). *Neurophysiologia*, *2*, 257-280.

Lynam, D. R., & Henry, B. (2001). The role of neuropsychological deficits in conduct disorders. In J. Hill, & B. Maughan (Eds.), *Conduct disorders in childhood and adolescence*. Cambridge, UK: Cambridge University Press.

Lynam, D., Moffitt, T., & Stouthamer-Loeber, M. (1993). Explaining the relation between IQ and delinquency: Class, race, test motivation, school failure, or self-control? *Journal of Abnormal Psychology, 102*, 187-196.

Manes, F., Sahakian, B., Clark, L., Rogers, R., Antoun, N., Aitken, M., et al. (2002). Decision-making processes following damage to prefrontal cortex. *Brain, 125,* 624-639.

Martel, M. M., Nigg, J. T., Wong, M. M., Fitzgerald, H. E., Jester, J. M., Puttler, L. I., et al. (2007). Childhood and adolescent resiliency, regulation, and executive functioning in relation to adolescent problems and competence in a high-risk sample. *Development and Psychopathology, 19,* 541-563.

Mayberg, H. S. (1997). Limbic-cortical dysregulation: A proposed model of depression. *The Journal of Neuropsychiatry and Clinical Neurosciences, 9,* 471-481.

McAuley, T., Chen, S., Goos, L., Schachar, R., & Crosbie, J. (2010). Is the behavior rating inventory of executive function more strongly associated with measures of impairment or executive function? *Journal of the International Neuropsychological Society, 16,* 495-505.

McDonald, R. P., & Ho, M-H. R. (2002). Principles and practice in reporting structural equation analyses. *Psychological Methods, 7,* 64-82.

Meehl, P. E. (1978). Theoretical risks and tabular asterisks: Sir Karl, Sir Ronald, and the slow progress of soft psychology. *Journal of Consulting and Clinical Psychology, 46,* 806-834.

Milner, B. (1963). Effects of different brain lesions on card sorting: The role of the frontal lobe. *Archives of Neurology, 9,* 90-100.

Milner, B. (1995). Aspects of human frontal lobe function. *Advances in Neurology, 66,* 67-84.

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

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.

Moffitt, T. E. (1993a). Adolescence-limited and life-course persistent antisocial behavior: A developmental taxonomy. *Psychological Review, 100,* 674-701.

Moffitt, T. E. (1993b). The neuropsychology of conduct disorder. *Development and Psychopathology, 5*, 135-151.

Moffitt, T. E. (2007). A review of research on the taxonomy of life-course persistent versus adolescence-limited antisocial behavior. In D. J. Flannery, A.T. Vazsonyi, & I. D. Waldman (Eds.), *The Cambridge handbook of violent behavior and aggression*. Cambridge: Cambridge University Press.

Morgan, A. B., & Lilienfeld, S. O. (2000). A meta-analytic review of the relation between antisocial behavior and neuropsychological measures of executive function. *Clinical Psychology Review*, *20*, 113-136.

Morrison, F. J., Ponitz, C. C., & McClelland, M. M. (2010). Self-regulation and academic achievement in the transition to school. In S. D. Calkins & M. A. Bell (Eds.), *Child development at the intersection of emotion and cognition.* Washington DC: American Psychological Association.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *126,* 220-246.

Nigg, J. T., Quamma, J. P., Greenberg, M. T., & Kusché, C. A. (1999). A two-year longitudinal study of neuropsychological and cognitive performance in relation to behavioral problems and competencies in elementary school children. *Journal of Abnormal Child Psychology, 27,* 51-63.

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

Owen, A. M., Evans, A. C., & Petrides, M. (1996). Evidence for a two-stage model of spatial working memory processing within the lateral frontal cortex: A positron emission tomography study. *Cerebral Cortex, 6,* 31-38.

Paschall, M. J., & Fishbein, D. H. (2002). Executive cognitive functioning and aggression: A public health perspective. *Aggression and Violent Behavior, 7,* 215-235.

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

Petrides, M., Alivasatos, B., Evans, A. C., & Meyer, E. (1993). Dissociation of human mid-dorsolateral from posterior dorsolateral frontal cortex in memory processing. *Proceedings of the National Academy of Sciences of the United States of America, 90*, 873-877.

Raaijmakers, M. A. J., Smidts, D. P., Sergeant, J. A., Maassen, G. H., Posthumus, J. A., van Engeland, H., & Matthys, W. (2008). Executive functions in preschool children with aggressive behavior: Impairments in inhibitory control. *Journal of Abnormal Child Psychology.*

Razza, R. A., & Blair, C. (2009). Associations among false-belief understanding, executive function, and social competence: A longitudinal analysis. *Journal of Applied Developmental Psychology, 30,* 332-343.

Reitan, R. M. (1971). Trail Making test results for normal and brain-damaged children. *Perceptual and Motor Skills, 33,* 575-581.

Reitan, R. M. (1979). *Manual for administration of neuropsychological test batteries for adults and children.* Tucson, AZ: Author.

Rhoades, B. L., Greenberg, M. T., & Domitrovich, C. E. (2009). The contribution of inhibitory control to preschoolers' social-emotional competence. *Journal of Applied Developmental Psychology, 30,* 310-320.

Ridderinkhof, K. R., & Van der Molen, M. W. (1995). A psychophysiological analysis of developmental differences in the ability to resist interference. *Child Development, 66,* 1040-1056.

Riggs, N. R., Blair, C. B., & Greenberg, M. T. (2003). Concurrent and 2-year longitudinal relations between executive function and the behavior of 1st and 2nd grade children. *Child Neuropsychology, 9,* 267-276.

Riggs, N. R., Jahromi, L. B., Razza, R. P., Dillworth-Bart, J. E., & Mueller, U. (2006). Executive function and the promotion of social-emotional competence. *Journal of Applied Developmental Psychology, 27,* 300-309.

Robbins, T. W. (1996). Dissociating executive functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London, 351*, 1463-1471.

Romer, D., Betancourt, L., Giannetta, J. M., Brodsky, N. L., Farrah, M., & Hurt, H. (2009). Executive cognitive functions and impulsivity as correlates of risk taking and problem behavior in preadolescents. *Neuropsychologia, 47,* 2916-2926.

Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related cognitive decline in normal adults. *Journal of Experimental Psychology: General, 132,* 566-594.

Séguin , J. R. (2004). Neurocognitive elements of antisocial behavior: Relevance of an orbitofrontal cortex account. *Brain and Cognition, 55,* 185-197.

Séguin, J. R., Arseneault, L., & Tremblay, R.E. (2007). The contribution of "cool" and "hot" components of decision-making in adolescence: Implications for developmental psychopathology. *Cognitive Development, 22*, 530-543.

Séguin , J. R., Arseneault, L., Boulerice, B., Harden, P. W., & Trembley, R. E. (2002). Response perseveration in adolescent boys with stable and unstable histories of physical aggression: The role of underlying processes. *Journal of Child Psychology and Psychiatry, 43,* 481-494.

Séguin, J. R., Boulerice, B., Harden, P. W., Tremblay, R. E., & Pihl, R. O. (1999). Executive functions and physical aggression after controlling for attention deficit hyperactivity disorder, general memory, and IQ. *Journal of Child Psychology and Psychiatry, 40*, 1197-1208.

Séguin, J. R., Nagin, D., Assaad, J-M., & Tremblay, R. E. (2004). Cognitive-neuropsychological function in chronic physical aggression and hyperactivity. *Journal of Abnormal Psychology, 113*, 603-613.

Séguin, J. R., Pihl, R. O., Boulerice, B., Tremblay, R. E., & Harden, P. W. (1996). Pain sensitivity and stability of physical aggression in boys. *Journal of Child Psychology and Psychiatry, 37*, 823-834.

Séguin, J. R., Pihl, R. O., Harden, P. W., Tremblay, R. E., & Boulerice, B. (1995). Cognitive and neuropsychological characteristics of physically aggressive boys. *Journal of Abnormal Psychology, 104*, 614-624.

Séguin, J. R., Sylvers, P., & Lilienfeld, S. O. (2007). The neuropsychology of violence. In D. J. Flannery, A. T. Vazsonyi, & I. D. Waldman (Eds.), *The Cambridge handbook of violent behavior and aggression*. Cambridge: Cambridge University Press.

Séguin, J. R., & Zelazo, P. D. (2005). Executive function in early physical aggression. In R. E. Trembley, W. W. Hartup, & J. Archer (Eds.), *Developmental origins of aggression*. New York: Guilford Press.

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. (1982). Specific impairments in planning. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *298,* 199-209.

Stanford, M. S., Greve, K. W., & Gerstle, J. E. (1997). Neuropsychological correlates of self-reported impulsive aggression in a college sample. *Personality and Individual Differences, 23*, 961-965.

Stordal, K. I., Mykletun, A., Asbjornsen, A., Egeland, J., Landro, N. I., Roness, A., et al. (2005). General psychopathology is more important for executive functioning than diagnosis. *Acta Psychiatrica Scandinavica, 111*, 22-28.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643-662.

Stuss, D. T. (1992). Biological and psychological development of executive functions. *Brain and Cognition, 20,* 8-23.

Stuss, D. T., & Benson, D. F. (1984). Neuropsychological studies of the frontal lobes. *Psychological Bulletin, 95*, 3-28.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes.* New York: Raven Press.

Tabachnick, B. G., & Fidell, L. S. (1996). *Using multivariate statistics (3rd ed.).* New York: Harper Collins.

Taylor, S. (1967). Aggressive behavior and physiological arousal as a function of provocation and the tendency to inhibit aggression. *Journal of Personality, 35*, 297-310.

Teichner, G., & Golden, C. J. (2000). The relationship of neuropsychological impairment to conduct disorder in adolescence: A conceptual review. *Aggression and Violent Behavior, 5*, 509-528.

Teuber, H. L. (1964). The riddle of the frontal lobe function in man. In J. M. Warren, & K. Akert (Eds.), *The frontal granular cortex and behavior* (pp. 410-477). New York: McGraw-Hill.

Teuber, H. L. (1972). Unity and diversity of frontal lobe functions. *Acta Neurobiologiae Experimentalis, 32*, 615-656.

Thompson, R. A. (1994). Emotion regulation: A theme in search of definition. In N. A. Fox (Ed.), *The development of emotion regulation: Biological and behavioral considerations. Monographs of the Society for Research in Child Development, 59*(2-3, Serial No. 240), 25-52.

Thompson, R. A., & Meyer, A. (2007). Socialization of emotion regulation in the family. In J. J. Gross (Ed.), *Handbook of emotion regulation.* New York: Guilford Press.

Van Boxtel, G. J. M., Van der Molen, M. W., Jennings, J. R., & Brunia, C. H. M. (2001). A psychophysiological analysis of inhibitory motor control in the stop-signal paradigm. *Biological Psychology, 58,* 229-262.

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.

Villemarette-Pittman, N. R., Stanford, M. S., & Greve, K. W. (2002). Language and executive function in self-reported impulsive aggression. *Personality and Individual Differences, 34,* 1533-1544.

Waber, D.P., De Moor, C., Forbes, P.W., Almli, C.R., Botteron, K.N., Leonard, G., et al. (2007). The NIH MRI study of normal brain development: Performance of a population based sample of healthy children aged 6 to 18 years on a neuropsychological battery. *Journal of the International Neuropsychological Society, 13,* 729-746.

Wang, L., LaBar, K. S., Smoski, M., Rosenthal, M. Z., Dolcos, F., Lynch, T. R., et al. (2008). Prefrontal mechanisms for executive control over emotional distraction are altered in major depression. *Psychiatry Research: Neuroimaging, 163,* 143-155.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). New York: Psychological Corporation.

Wechsler, D. (1997). *Wechsler Adult Intelligence Scale* (3rd ed.). New York: Psychological Corporation.

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence.* New York: Psychological Corporation.

Wellman, H. M. (1990). *The child's theory of mind.* Cambridge, MA: MIT Press.

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.

Wernicke, C. (1874). *Der aphasische Symptomencomplex*. Breslau: Cohn und Weigert.

Zahn-Waxler, C. (1993). Warriors and worriers: Gender and psychopathology. *Development and Psychopathology, 5*, 79-89.

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., Carlson, S. M., & Kesek, A. (2008). Development of executive function in early childhood. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience 2nd edition.* (pp. 553-574). Cambridge, MA: The MIT Press.

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., & Cunningham, W. A. (2007). Executive function: Mechanisms underlying emotion regulation. In J. J. Gross (Ed.), *Handbook of emotion regulation.* New York: The Guilford Press.

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445-469). Oxford, UK: 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 in Child Development, 68*(3).