Roles of Attention Shifting and Inhibitory Control in Fourth-Grade Reading Comprehension

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ABSTRACT

Executive functioning (EF) refers to a set of higher order, core cognitive processes that facilitate planning, problem solving, and the initiation and maintenance of goal-directed behavior. Although recent research has established the importance of EF for word reading development in early childhood, few studies have investigated the role of EF in reading comprehension during middle childhood. This study investigated the relations between two specific dimensions of EF—attention shifting and inhibitory control—and reading comprehension for students in fourth grade (N = 120). Specifically, we used path analysis to investigate the direct, unique associations of attention shifting and inhibitory control with reading comprehension as well as the indirect associations with reading comprehension via language comprehension and word reading, controlling for working memory, processing speed, and phonological awareness. Results indicated that both attention shifting and inhibitory control demonstrated unique direct associations with reading comprehension. Attention shifting also demonstrated a significant indirect association via language comprehension. Findings support growing evidence for the importance of these EF dimensions to reading, raise questions about potential mechanisms underlying links between EF and reading comprehension, and offer implications for understanding and addressing reading comprehension difficulties.

Reading comprehension is a complex and multifaceted cognitive process that draws on a wide range of skills and knowledge (RAND Reading Study Group, 2002). In addition to the widely accepted roles of language comprehension and word reading skills (Gough & Tunmer, 1986; Perfetti, Landi, & Oakhill, 2005), it is likely that domain-general cognitive skills are required for successful comprehension of text. In particular, executive functioning (EF) may play multiple important roles in reading comprehension. Research on EF has begun to establish its importance in the development of basic literacy skills in early childhood (e.g., Blair & Razza, 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010). Although EF undergoes rapid development during these early years, it continues to develop throughout middle childhood and adolescence (for a review, see Best, Miller, & Jones, 2009), raising the need to investigate the ways in which it influences the more advanced cognitive process of reading comprehension for older students.

EF is an umbrella term for a set of higher order, cognitive processes that facilitate planning, problem solving, and the initiation and maintenance of goal-directed behavior (Pennington & Ozonoff, 1996). EF includes three related, yet distinct, core cognitive dimensions: attention shifting, inhibitory control, and working memory/

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updating (e.g., Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). This simultaneous “unity and diversity” (Miyake et al., 2000, p. 49) of EF raises the possibility that different dimensions of EF play unique roles in reading comprehension and/or make distinct contributions to the development of the componential skills involved in reading comprehension. Although the role of working memory in reading comprehension is well established (e.g., Cain, Oakhill, & Bryant, 2004; Daneman & Carpenter, 1980; Hannon, 2012; Just & Carpenter, 1992; Swanson & Siegel, 2001), the roles of attention shifting and inhibitory control are less clear. In particular, there is limited data on whether these latter dimensions of EF contribute to reading comprehension beyond the well-established contributions of language comprehension and word reading skills. It is also unknown whether these dimensions make indirect contributions to reading comprehension by facilitating language comprehension and/or word reading.

The current study was designed to investigate the extent to which two dimensions of EF—attention shifting and inhibitory control—make direct and indirect contributions to reading comprehension for students in fourth grade. Specifically, we used path analysis to investigate whether these dimensions predicted reading comprehension directly and/or indirectly via the two best-known componential skills underlying reading comprehension: language comprehension and word reading. This research was designed to build on growing evidence for the roles of inhibitory control and attention shifting in emergent literacy skills during preschool and kindergarten (e.g., Blair & Razza, 2007; Welsh et al., 2010) and extend it to reading comprehension during the upper elementary grades, when students transition from learning to read to reading to learn (e.g., Chall, 1983). In so doing, we aim to inform instructional efforts that address reading comprehension difficulties in the upper elementary grades by shedding light on the extent to which they should account for co-occurring EF weaknesses.

EF: Working Memory, Attention Shifting, and Inhibitory Control

Researchers have conceptualized EF as represented by a core set of three higher order cognitive dimensions: working memory/updating, inhibitory control, and attention shifting (Fisk & Sharp, 2004; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). In a broad sense, working memory is considered the ability to hold and manipulate information in the mind (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980) and is typically assessed using tasks in which participants are presented with a sequence of visual or verbal information and required to monitor and update the information in some manner.

Attention shifting (sometimes called set shifting) is the extent to which one can volitionally shift his or her attention between different tasks, operations, or cognitive sets (Miyake et al., 2000; Monsell, 1996). For instance, attention shifting is represented by the degree to which one can flexibly and efficiently shift from the demands of an old cognitive set or rule to those of a new one, as commonly measured by preservative errors (i.e., errors adhering to a previous rule after a change in rules) on the Wisconsin Card Sorting Test (see the Measures section).

Finally, inhibitory control is the ability to withhold a well-learned prepotent response to enact a subdominant response. As discussed by Nigg (2000), there is likely a taxonomy of different types of inhibitory control; however, the Stroop paradigm represents a prototypical example. Here, when presented with a color word (e.g., *blue*) printed in a color of ink that differs from the meaning of the word (e.g., red ink), inhibitory control represents the extent to which an individual can inhibit the prepotent tendency to read the word and instead adopt the subdominant response of stating the color of ink in which the color word is printed.

There is evidence of both unity and diversity among these three EF dimensions at both the neurocognitive and broad behavioral levels. Functional studies of neural activity (e.g., functional magnetic resonance imaging, positron emission tomography) suggest that some regions recruited during EF tasks are common across the different EF dimensions (e.g., posterior frontolateral and parietal cortices; Collette et al., 2005; Derrfuss, Brass, Neumann, & von Cramon, 2005; Wager & Smith, 2003). In addition, factor-analytic studies of EF performance show moderate to strong positive correlations between latent factors purported to measure working memory, attention shifting, and inhibitory control (Lehto et al., 2003; Miyake et al., 2000). Yet, growing evidence suggests that some of the neural processes implicated in EF tasks may also be unique to each EF dimension (see Collette et al., 2005; Wager & Smith, 2003).

Behavioral evidence from recent factor-analytic work also suggests that there may, in fact, be more diversity across latent representations of working memory, attention shifting, and inhibitory control than previously suspected. For example, factor-analytic studies that account for variance associated with more general cognitive processes (e.g., processing speed) that are common across EF tasks find that the correlations among EF dimensions are often substantially attenuated, after adjusting for these more general cognitive processes (Huizinga, Dolan, & van der Molen, 2006; van der

Sluis, de Jong, & van der Leij, 2007). Taken together, these findings raise the possibility that these three core processes of EF may be diverse dimensions that have unique relations with the complex cognitive process of reading comprehension.

Roles of EF in Reading for Understanding

Reading comprehension has been defined by the RAND Reading Study Group (2002) as "the process of simultaneously extracting and constructing meaning through interaction and involvement with written language" (p. xiii). According to this view, reading is a developmental process that involves the interaction among a reader, a text, and an activity, all situated within a particular sociocultural context, with each of these four serving as sources of variability in reading comprehension. In the current study, we are concerned centrally with the role of reader characteristics (i.e., attention shifting, inhibitory control), while attending in our design (e.g., measurement selection) to the other dimensions as they relate to grade-level expectations for what texts are read, for what purposes, and in what contexts.

Reading comprehension is also considered by many to be a componential process influenced by, among others, two major skill domains: word reading and language comprehension (National Institute of Child Health and Human Development, 2000). Word reading involves the translation of printed words into oral language, whereas language comprehension entails the processes, skills, and knowledge involved in understanding oral language. In particular, the simple view of reading considers reading comprehension to be captured parsimoniously as the product of these two component skills (Gough & Tunmer, 1986; Hoover & Gough, 1990). Other models specify which component skills influence language comprehension and word reading, while retaining the importance of these two major domains (e.g., Joshi & Aaron, 2000; Perfetti et al., 2005; Scarborough, 2001).

Around fourth grade, the relative weight of these two component domains shifts, such that language comprehension begins to have a greater contribution to reading comprehension than word reading (e.g., Catts, Hogan, & Adolf, 2005; Hoover & Gough, 1990). By this age, reading comprehension and word reading have become partially disassociated, such that some readers begin to demonstrate specific reading comprehension difficulties (i.e., difficulties with reading comprehension in the presence of adequate word reading skills; e.g., Cain & Oakhill, 2006). Despite this consensus that word reading and language comprehension are essential for reading comprehension, much less is known about the underlying cognitive skills that predict each of these components of reading comprehension.

Reading researchers have long acknowledged one dimension of EF, working memory, as important for both the word reading and the language comprehension components of reading comprehension (e.g., Daneman & Carpenter, 1980; Swanson & Siegel, 2001). Research suggests that working memory is necessary to keep initial phonemes in memory while sounding out the rest of a word, to retrieve new word meanings while holding previously read word meanings in memory, and to integrate information across individual word meanings in sentences while holding those word meanings in memory. These processes thus implicate working memory in both word reading (e.g., Christopher et al., 2012; de Jong, 1998; Gottardo, Stanovich, & Siegel, 1996; Hansen & Bowey, 1994) and reading comprehension (e.g., Cain et al., 2004; Daneman & Carpenter, 1980; Hannon, 2012; Just & Carpenter, 1992; Swanson & Siegel, 2001).

Drawing on this evidence, theories of reading comprehension have frequently acknowledged the role of working memory, while paying much less attention to inhibitory control and attention shifting. For instance, Kintsch's (1988) construction–integration model incorporates working memory as a limited cognitive resource without including other dimensions of EF. The LaBerge–Samuels' model of automatic information processing in reading addresses attention and working memory as important constraints in reading but neglects inhibitory control and fails to specify implications for understanding individual differences in reading comprehension (LaBerge & Samuels, 1974; Samuels, 1994).

Some emerging evidence supports the relation between inhibitory control and foundational skills involved in word reading. For instance, one recent longitudinal study found that inhibitory control in kindergarten predicted phonemic awareness and letter knowledge (two strong predictors of word reading), after controlling for preschool and kindergarten intelligence and other confounds, in a sample of children from low-income homes (Blair & Razza, 2007). Similarly, a study of students in seventh grade found that inhibitory control differentiated students with word reading disabilities from typically developing readers (Protopapas, Archonti, & Skaloumbakas, 2007). Although less is known about the role of inhibitory control in reading comprehension across the full range of learners, it may be important, for instance, in activating the relevant meaning for a polysemous word while inhibiting other meanings (Barnes, Faulkner, Wilkinson, & Dennis, 2004) and in ignoring irrelevant information when building a coherent mental representation of a complete text (Cain, 2006; De Beni & Palladino, 2000; Kintsch, 1988).

Attention shifting has similarly been implicated in word reading. For instance, one longitudinal study found that growth in attentional control during prekindergarten made a unique contribution to word reading accuracy and efficiency at the end of kindergarten, beyond the contributions of prekindergarten growth in working memory and emergent literacy skills (Welsh et al., 2010). Likewise, a recent study using structural equation modeling with data from Dutch students ages 9–12 found that attention shifting predicted word reading efficiency above and beyond working memory and nonexecutive aspects of the EF tasks, such as naming speed (van der Sluis et al., 2007). However, this study also found that these nonexecutive cognitive skills explained more variation in word reading efficiency than did attention shifting or working memory, highlighting the importance of controlling for processing speed when seeking to isolate the unique contributions of EF to reading. Although fewer studies have investigated the role of attention shifting in reading comprehension processes, it is likely that attention shifting is involved, for instance, in integrating new linguistic information from the text with background knowledge, in monitoring real-time comprehension, and in using metacognitive comprehension strategies (Torgesen, 1994).

In addition to studies examining each EF dimension separately, three recent studies from one research group examined the relation between reading comprehension and complex EF tasks that simultaneously tap all three dimensions (Cutting, Materek, Cole, Levine, & Mahone, 2009; Locascio, Mahone, Eason, & Cutting, 2010; Sesma, Mahone, Levine, Eason, & Cutting, 2009). For instance, a study of 9–14-year-olds found that students with specific reading comprehension difficulties demonstrated prominent weaknesses on the Tower of London task, a complex EF measure involving spatial planning, rule learning, and inhibition of impulsive responding, and on Elithorn's perceptual maze test, a complex measure involving planning, organization, and monitoring abilities (Cutting et al., 2009). Similar weaknesses were found for students with specific reading comprehension difficulties on a latent EF planning factor (Locascio et al., 2010). A third study by this research group found that performance on the Tower of London task predicted reading comprehension, after controlling for parent-rated attention, phonemic decoding, fluency, and vocabulary (Sesma et al., 2009).

Although these studies provide good support for the role of EF generally in reading comprehension, they do not isolate the unique contributions of attention shifting and inhibitory control. Building more specified models of reading comprehension and informing targeted instructional approaches will require identifying the particular roles of these two dimensions of EF in the reading process.

Overall, the existing research provides good reason to believe that inhibitory control and attention shifting play roles in reading comprehension, beyond the established contribution of working memory, but leaves several open questions about the specifics of these relations. First and foremost, most of the existing studies have focused on word reading and its prerequisites, raising questions about whether and how attention shifting and inhibitory control play into reading comprehension. In addition, the few studies that have examined relations between EF and reading comprehension have used complex measures tapping multiple dimensions, so the unique contributions of attention shifting and inhibitory control are unknown. Finally, the contributions of attention shifting and inhibitory control to language comprehension and the extent to which language comprehension mediates relations between these EF dimensions and reading comprehension have rarely been investigated. Based on prior evidence, we hypothesized that the contributions of inhibitory control and attention shifting to reading comprehension are partially mediated by word reading, but we also hypothesized that inhibitory control and attention shifting make other contributions to reading comprehension, both by facilitating language comprehension and by facilitating reading comprehension directly.

Current Study

The current study was designed to shed light on the relations between two dimensions of EF (attention shifting and inhibitory control) and reading comprehension for students in fourth grade. Specifically, we sought to extend the literature demonstrating relations between EF and basic literacy skills in early childhood to reading comprehension skills in middle childhood, while also investigating whether such relations are mediated by one or both of the two major determinants of reading comprehension: language comprehension and word reading. In so doing, we aimed to inform the development of more specified models of reading comprehension that can support instructional research efforts to address reading comprehension difficulties.

Two related research questions guided this study:

1. Do attention shifting and inhibitory control make unique direct contributions to reading comprehension, beyond the contributions of language comprehension, word reading, and control variables for related cognitive processes (i.e., working memory, processing speed, phonological awareness)?
2. Do attention shifting and inhibitory control make indirect contributions to reading comprehension via language comprehension and/or word reading?

Method

Participants

The data in this study were collected as part of an ongoing longitudinal research project designed to examine the developmental course and cognitive predictors of academic abilities in a cohort of diverse students in an urban context (e.g., Kieffer & Vukovic, 2012a, 2012b). The analytic sample included 120 students who participated in the grade 4 data collection, at which point the mean age of participants was 9 years, 11 months (*SD* = 6 months). Consistent with the purposes of the broader study, the participating students attended two urban, Title I schools in New York City, were from low-income backgrounds, and were predominantly students of color. Specifically, based on school reports, participating students were 69% Latino, 26% African American, 2% Asian, and 3% white. Sixty-one percent of the sample (74 students) spoke a language other than English at home, with Spanish the most prominent home language (68 students). Results for the relations of interest were similar across language groups, so we report results for the entire sample. The language of instruction in fourth grade was English.

According to school records, 93% of students received free or reduced-price lunch. Fifty-seven percent of the participants (68) were male. The two schools reported using two different reading programs in grades 1–4, both of which could be described as phonics based, with strong emphases on systematic and explicit instruction in phonological awareness and sound–symbol correspondences.

Measures

Reading Comprehension

We used the Gates–MacGinitie Reading Comprehension Test (MacGinitie, MacGinitie, Maria, & Dreyer, 2000) to assess text-level reading comprehension. With this test, participants are provided 35 minutes to read 11 short passages and answer 48 multiple-choice questions related to the passages. At the grade 4 level, the passages are all selected from published books or periodicals and contain natural science, social science, and fictional content, written in both narrative and nonnarrative modes. The publisher reports a Kuder–Richardson formula 20 reliability coefficient of .93 for the grade 4 test.

Attention Shifting

We used the 64-card version of the Wisconsin Card Sorting Test (Kongs, Thompson, Iverson, & Heaton, 2000) to assess attention shifting. With this test, students are given cards that display different shapes with differing numbers and colors and are asked to sort the cards along an unspecified dimension (e.g., shape). Students are not told the sorting rule but are provided with feedback as to whether a given move is correct or incorrect. After 10 correct sorting moves, the sorting rule changes, and students are given feedback consistent with a new sorting rule (e.g., color). The 64-card version is an abbreviated version of the standard Wisconsin Card Sorting Test, which shortens administration time while retaining the same task requirements.

Although a variety of scores are available, we used the number of perseverative errors (i.e., errors in which students apply a previous rule after receiving feedback that it is no longer active) as an indicator of difficulty with attention shifting. To facilitate interpretation, we used a linear transformation in which we calculated *z*-scores and multiplied them by −1 so higher scores represent better attention shifting, while retaining the original distribution of student performance. The publisher reports adequate reliability for the perseverative error scores (generalizability coefficient = .76) as well as extensive validity evidence.

Inhibitory Control

We used a researcher-developed measure, the number–quantity Stroop, based on previous research (Bull & Scerif, 2001). This task, also known as the quantity inhibition task (van der Sluis et al., 2007; Wang, Tasi, & Yang, 2012), builds on the traditional color–word Stroop paradigm described previously, while eliminating the influence of reading skills. In this task, students complete three conditions, in each of which students are asked to name the quantity presented:

1. A baseline condition in which students are presented with a series of Xs (e.g., XX, XXX)
2. A congruent condition in which students are presented with a series in which the digits corresponds to the quantity (e.g., 22, 333)
3. An incongruent condition in which students are presented with a series in which the digits do not correspond to the quantity (e.g., 222, 33)

The third condition requires inhibition of the automatic response to name the digits to provide the quantity of digits presented.

Each condition included a series of 20 stimuli in two rows, and the time to complete the series of 20 was measured. To assess inhibitory control, we used an interference score, which was the difference in time between the incongruent and baseline conditions, with positive differences representing weaker inhibitory control. As with attention shifting, we used a linear transformation in which we calculated *z*-scores and multiplied them by −1 so higher scores represent better inhibitory control. Although we were unable to estimate reliability for the current sample, prior research estimates test–retest reliability at .81 for students of this age (Wang et al., 2012).

Language Comprehension

We assessed language comprehension using the oral comprehension subtest from the Woodcock–Johnson III (WJ–III) battery (Woodcock, Schrank, McGrew, & Mather, 2007). With this test, students listen to short passages and then supply the missing final word using syntactic and semantic clues (e.g., "Without a doubt, his novels are more complex than the novels of many other contemporary ___."). The publisher reports reliability between .78 and .80 for students in grade 4.

Word Reading

We assessed word reading using the letter–word identification test from the WJ–III research edition (Woodcock, McGrew, & Mather, 1999). With this test, students identify and pronounce isolated letters (e.g., *g*, *r*) and words of increasing difficulty (e.g., *cat*, *palm*). The publisher reports reliability between .96 and .98.

Control Measures

Controls for related cognitive skills included measures of phonological awareness, working memory, and processing speed. Phonological awareness was measured using the Comprehensive Test of Phonological Processing's elision subtest (Wagner, Torgesen, & Rashotte, 1999). This test measures the extent to which a student can say a word and then say what is left after dropping designated sounds, including syllables, initial sounds, and blends (e.g., "Say *bold*....Now say *bold* without saying /b/."). The publisher reports reliability between .89 and .92.

Working memory was assessed using the visual matrix subtest from the Swanson Cognitive Processing Test (Swanson, 1996). With this individually administered task, students study the pattern of dots in a matrix for five seconds and then answer a question about the matrix (e.g., "Are there any dots in the first row?"). Students then re-create the pattern on a blank matrix. The publisher reports reliability at .73.

Processing speed was assessed using the visual matching subtest of the WJ–III (Woodcock et al., 2007). With this test, students have three minutes to circle two identical numbers in rows of numbers. Numbers range from one to three digits. The publisher reports reliability between .87 and .88.

Procedure

Assessments of the students occurred in the winter of their fourth-grade year. They were individually assessed for all tasks except for reading comprehension, which was group-administered in the students' classrooms. Research assistants conducted the assessments in the schools after completing an intensive four-hour training workshop on standardized administration, which included demonstrating 100% accuracy during mock administrations. In addition, a school psychology doctoral student was present during data collection so questions and coaching occurred when necessary throughout data collection.

Data Analytic Plan

Overview of Path Analysis

Multivariate path analyses implemented in M*plus* 7 (Muthén & Muthén, 2012) was used to investigate multiple simultaneous relations among the variables of interest, while estimating both direct and indirect (partially mediated) associations of each EF dimension with reading comprehension. Path analysis can be thought of as a subtype of structural equation modeling, in which all constructs in the structural model are represented by variables that have a single, observed indicator (e.g., Bollen, 1989; Bozionelos, 2003).

Path analysis has several advantages over the ordinary least squares (OLS) multiple regression approaches that have been used in prior research on EF and reading comprehension (e.g., Sesma et al., 2009), three of which are particularly relevant to this study. First, whereas OLS regression models only allow independent predictors for a single dependent outcome, path analysis allows researchers to specify that one or more variables are simultaneously dependent variables in one relationship and independent variables in another (i.e., serving as a mediating variable to a full or partial extent). Here, attention shifting and inhibitory control were specified as independent variables, whereas the intermediate reading-related skills hypothesized to act as mediators (i.e., language comprehension, word reading) were specified as proximal outcomes for attention shifting and inhibitory control, as well as predictors of the distal outcome of reading comprehension. Second, unlike OLS regression, path analysis allows researchers to directly estimate the magnitude and test the significance of indirect associations, which was used in the current study to evaluate the indirect associations of inhibitory control and attention shifting with reading comprehension via the hypothesized mediators. Third, path analysis can utilize full information maximum likelihood estimation to account for missing data appropriately (Enders & Bandalos, 2001); this prevented the exclusion of 10 cases with data missing because of administrator error on the attention-shifting measure.

Hypothesized Model

The research questions were addressed by fitting the hypothesized path analysis model displayed in Figure 1 and evaluating the paths of interest. Variables are represented with labeled rectangles, regression paths of interest are represented with single-headed arrows, and covariances among the predictors and the residual covariance between the mediators are represented as double-headed arrows. As shown, inhibitory control and attention shifting were hypothesized to predict the mediating variables of language comprehension and word reading, each of which in turn was hypothesized to predict the distal outcome of reading comprehension, after accounting for the associations with the controls. The box labeled "Controls" represents three observed variables (phonological awareness, working memory, and processing speed), each of which is hypothesized to correlate with the other predictors and to predict word reading, language comprehension, and reading comprehension.

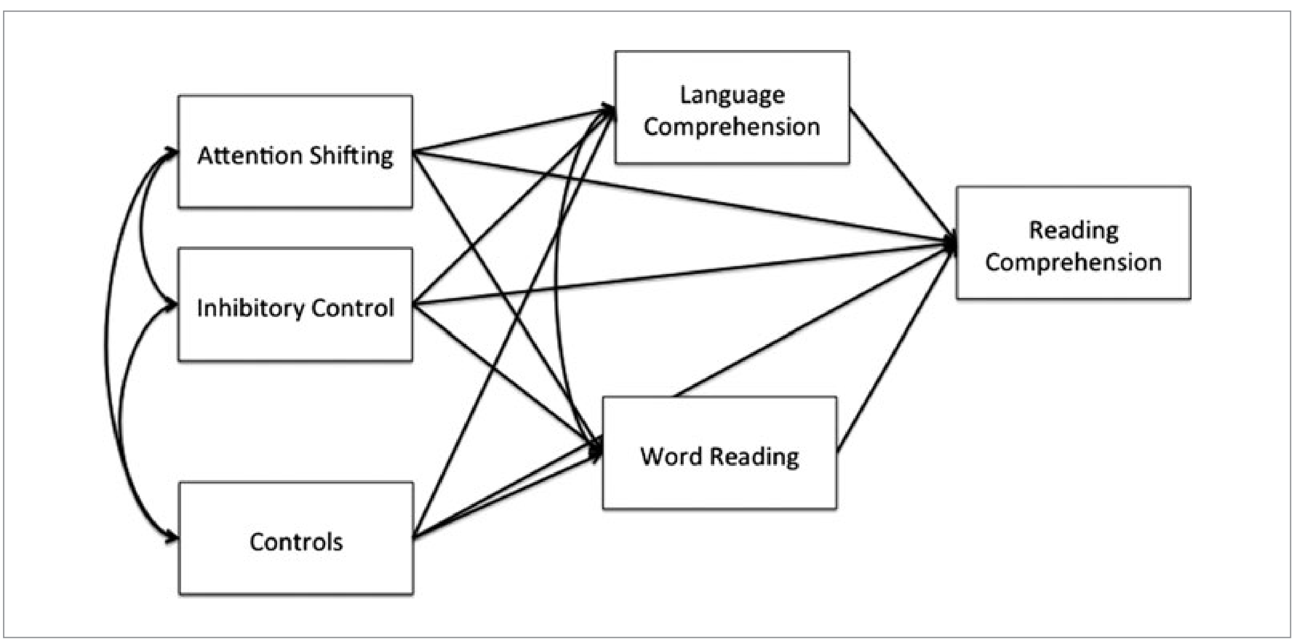
To address the research questions, the statistical significance of each of the paths of interest was evaluated along with the indirect associations via the mediators (i.e., the products of the fitted parameters comprising the respective pathways). The magnitudes of the effect sizes of interest were also evaluated using Cohen's (1992) conventions, under which standardized regression coefficients near .10 are considered small, near .30 are considered moderate, and near .50 are considered large. In addition, the goodness of fit of the final, reduced model (i.e., a model from which the nonsignificant associations have been removed for parsimony) was evaluated using the root mean square error of approximation (RMSEA) and comparative fit index (CFI).

Accounting for Small Sample Size

Our sample size (N = 120) is relatively small compared with some rules of thumb for path analyses and structural equation modeling (e.g., Klein, 2011). Small sample size can raise four issues in path analysis: bias in parameter estimates, bias in standard errors and associated significance tests, bias in goodness-of-fit statistics, and limitations in statistical power. We addressed each of these.

First, to assess the potential for bias in parameter estimates, given our sample size and hypothesized model, we conducted a Monte Carlo simulation following Muthén and Muthén (2002) and found little reason to suspect parameter bias (see the Appendix). Second, we assessed the potential for bias in standard errors using this same Monte Carlo simulation and found little reason to suspect standard error bias (see the Appendix). Nonetheless, to affirm the robustness of our significance tests, we used bootstrapping with 1,000 draws to produce 95% confidence intervals for

FIGURE 1
Hypothesized Path Model for Direct and Indirect Associations of Attention Shifting and Inhibitory Control With Reading Comprehension, After Accounting for Controls



Note. The box labeled "Controls" represents observed variables for phonological awareness, working memory, and processing speed, each of which has a covariance with attention shifting and inhibitory control and regression paths to word reading, language comprehension, and reading comprehension.

the parameter estimates. This approach has the advantage of minimizing bias in significance testing in small samples (e.g., 77 participants in Ievers-Landis, Burant, & Hazen, 2011). Bootstrapping is particularly valuable for estimating indirect associations, for which traditional z-statistics are known to be biased (e.g., MacKinnon, Fairchild, & Fritz, 2007). Third, to account for the possibility of bias in the goodness-of-fit statistics for our final model, we used Swain's (1975) correction of the maximum likelihood chi-square statistic for the estimation of the RMSEA and CFI, which has been shown to produce reliable estimates for different degrees of model misspecification at sample sizes as small as 50 (Herzog & Boomsma, 2009). Fourth, we assessed the statistical power to detect the relations of interest using the aforementioned Monte Carlo simulation (see the Appendix).

TABLE 2
Correlations Among Measures (*N* = 120)

Construct	1	2	3	4	5	6	7
1. Reading comprehension							
2. Attention shifting	.33						
3. Inhibitory control	.32	.12					
4. Language comprehension	.53	.31	.16				
5. Word reading	.54	.17	.16	.52			
6. Phonological awareness	.32	.18	.13	.30	.46		
7. Working memory	.13	.02	.15	.17	.22	.20	
8. Processing speed	.30	.13	.14	.30	.18	.10	.21

Note. $p < .05$ for $rs > .18$.

Results

Preliminary Analyses

Table 1 provides means and standard deviations in raw scores and standard scores (when available) on all measures. As shown, the sample performed below average based on national norms in reading comprehension, working memory, and language comprehension, while performing closer to the national average in attention shifting, letter–word identification, phonological awareness, and processing speed.

Table 2 provides zero-order correlations among the measures. Relevant to the unity and diversity of EF, the three dimensions of EF (attention shifting, inhibitory control, and working memory) had small (<.16) and nonsignificant correlations with one another. Relevant to our research questions, both attention shifting and inhibitory control had moderate, significant correlations with reading comprehension (r = .33 and .32, respectively) but small and nonsignificant correlations with word reading (r = .17 and .16, respectively). Attention shifting also had a moderate, significant correlation with language comprehension (r = .31), whereas inhibitory control had a small, nonsignificant correlation with language comprehension (r = .16).

Path Analyses

Multivariate path analysis was used to investigate the direct and indirect associations of attention shifting and inhibitory control with reading comprehension.

TABLE 1
Sample Means (and standard deviations) on All Measures (*N* = 120)

Construct	Measure	Raw score	Standard score
Reading comprehension	Gates-MacGinitie Reading Test IV: Reading comprehension	22.60 (10.15)	90.86 (12.69)
Attention shifting	Wisconsin Card Sort Test, 64-card version: Perseverative errors	12.92 (6.65)	95.77 (21.73)
Inhibitory control	Stroop digit–number interference	8.02 (7.18)	
Language comprehension	Woodcock–Johnson III: Oral comprehension	15.41 (4.32)	87.85 (13.94)
Word reading	Woodcock–Johnson III: Letter–word Identification	48.41 (8.08)	97.01 (13.15)
Phonological awareness	Comprehensive Test of Phonological Processing: Elision	12.48 (5.00)	95.09 (16.19)
Working memory	Swanson Cognitive Processing Test: Visual matrices	3.01 (1.53)	89.46 (11.29)
Processing speed	Woodcock–Johnson III: Visual matching	36.09 (5.81)	94.54 (15.71)

First, to determine which of the hypothesized paths were significant, a full model based on the hypothesized model displayed in Figure 1 was fitted to the data. Second, to determine the final estimates of the magnitudes of the significant associations and to evaluate the fit of the ultimate model, a final, reduced model was fitted excluding the paths and covariances that were found to be nonsignificant in the full model.

As shown in Table 3, the full model's results indicated that attention shifting and inhibitory control each had

TABLE 3
Selected Results for Path Analysis Models Predicting Reading Comprehension by Attention Shifting, Inhibitory Control, Language Comprehension, and Word Reading, Controlling for Working Memory, Processing Speed, and Phonological Awareness (N = 120)

	Full model		Final, reduced model		
Path	Standardized $\hat{\beta}$	z	Standardized $\hat{\beta}$	z	Bootstrapped 95% confidence interval
Direct associations with reading comprehension					
Attention shifting	.16	2.04*	.17	2.24*	(.01, .30)
Inhibitory control	.19	2.57*	.21	2.62**	(.09, .40)
Language comprehension	.24	2.85**	.27	3.55***	(.12, .43)
Word reading	.32	3.67***	.35	4.06***	(.18, .50)
Working memory	−.05	−0.77			
Processing speed	.13	1.50			
Phonological awareness	.04	0.56			
Indirect associations with reading comprehension					
Attention shifting via language comprehension	.05	1.86	.06	1.90	(.01, .11)
Attention shifting via word reading	.02	0.71			
Inhibitory control via language comprehension	.02	0.71			
Inhibitory control via word reading	.02	0.60			
Direct associations with language comprehension					
Attention shifting	.23	2.44*	.20	2.22*	(.02, .36)
Inhibitory control	.06	0.81			
Working memory	.07	0.81			
Processing speed	.23	2.61**	.20	2.61**	(.05, .34)
Phonological awareness	.21	2.41*	.26	2.81**	(.08, .43)
Direct associations with word reading					
Attention shifting	.07	0.74			
Inhibitory control	.07	0.63			
Working memory	.11	1.13			
Processing speed	.10	0.97			
Phonological awareness	.40	4.97***	.46	5.34***	(.29, .62)

Note. The full model also included all covariances between predictors and a residual covariance between language comprehension and word reading. The final, reduced model included only the significant residual covariance between language comprehension and word reading because the covariances among the predictors were nonsignificant.
*p < .05. **p < .01. ***p < .001.

unique significant direct associations with reading comprehension (p = .042 and .010, respectively), after controlling for language comprehension, word reading, working memory, processing speed, and phonological awareness. Attention shifting also had a significant association with language comprehension and, thereby, an indirect association with reading comprehension via language comprehension; the bootstrapped 95% confidence interval for this association did not cover 0, indicating that it was statistically significant (CI = .01 to .12). Inhibitory control had neither a significant indirect association with reading comprehension via language comprehension (bootstrapped 95% CI = −.03 to .06) nor an indirect association with reading comprehension via word reading (bootstrapped 95% CI = −.04 to .09). In addition, attention shifting did not have a significant indirect association with reading comprehension via word reading (bootstrapped 95% CI = −.04 to .10).

The results for the final, reduced model exclude the paths and covariances found to be nonsignificant in the full model. As shown, the key findings remained the same. In particular, attention shifting had a significant, small to moderate direct association with reading comprehension (standardized regression coefficient = .17, z = 2.24, bootstrapped 95% CI = .01 to .30), as did inhibitory control (standardized regression coefficient = .21, z = 2.62, bootstrapped 95% CI = .09 to .40). Attention shifting also had a significant, small indirect association with reading comprehension via language comprehension (standard regression coefficient = .06, bootstrapped 95% CI = .01 to .11). The goodness of fit of the reduced model was acceptable, based on traditional indexes (RMSEA = .078, CFI = .904) and Swain-corrected indexes that account for the small sample size (Swain-corrected RMSEA = .075, Swain-corrected CFI = .911).

Discussion

This study was designed to investigate the direct and indirect roles of two dimensions of EF—attention shifting and inhibitory control—in reading comprehension for students in fourth grade. Our findings support emerging evidence for the importance of these two distinct dimensions of EF in early academic development and extend this evidence to reading comprehension during the upper elementary grades, when students make the transition from learning to read to reading to learn. Specifically, we found that both attention shifting and inhibitory control make significant, small to moderate unique contributions to reading comprehension above and beyond word reading, language comprehension, working memory, processing speed, and phonological awareness. We also found that attention shifting makes a small, significant indirect contribution to reading comprehension via language comprehension, suggesting one possible mechanism by which this dimension of EF may facilitate reading for understanding.

In a somewhat surprising result, we found that attention shifting, inhibitory control, and working memory were weakly and nonsignificantly correlated with one another in our sample. This suggests more diversity than unity among these dimensions of EF. Notably, although researchers commonly create latent factors hypothesized to explain common variance across EF tasks, weak to moderate correlations across observed tasks are not uncommon. Indeed, in Miyake and colleagues' (2000) seminal EF measurement paper—perhaps the most cited in the EF literature—the average correlation between the observed EF tasks was only approximately .16, with cross-task correlations ranging from weak (at times, negative) and statistically nonsignificant to statistically significant and moderate (i.e., r = .34). Thus, our present findings are by no means anomalous. The weak associations across the EF tasks in our data support the examination of attention shifting, inhibitory control, and working memory individually as predictors of reading comprehension. We would nonetheless argue that these abilities can still be grouped conceptually under the umbrella of EF as core cognitive processes involved in planning, problem solving, and the initiation and maintenance of goal-directed behavior.

Together, these findings suggest that models of reading comprehension should incorporate dimensions of EF beyond working memory and raise hypotheses about the specific roles that attention shifting and inhibitory control may play in reading for understanding. They also offer implications for additional research to improve our understanding of how to identify, prevent, and address reading comprehension difficulties.

Role of Inhibitory Control in Reading for Understanding: Some Hypotheses

Our first main finding is that inhibitory control (i.e., the ability to withhold a well-learned prepotent response to enact a subdominant response) had a direct association but no indirect associations (through word reading or language comprehension) with reading comprehension, after accounting for language comprehension, word reading, phonological awareness, working memory, and processing speed. We interpret this finding as raising the hypothesis that inhibitory control may play a prominent role in the facilitation of the top-down cognitive processes required for reading comprehension. To understand text, readers must not only be able to make accurate inferences and synthesize information across propositions (e.g., Cain & Oakhill, 1999) but also suppress irrelevant information and inhibit inappropriate inferences (e.g., Cain, 2006; Kintsch, 1988). For instance, some evidence suggests that students with specific comprehension difficulties are less skilled at suppressing contextually irrelevant meanings of polysemous words (Barnes et al., 2004) and more likely to recall irrelevant information from a passage (De Beni & Palladino, 2000).

Our findings also raise the possibility that inhibitory control plays a role in the development of strategic reading comprehension over time, a hypothesis that calls for future longitudinal research. Learning to read strategically requires students to acquire an appropriate set of cognitive strategies and processes, to learn to use those strategies and processes flexibly in contextually appropriate ways, and to monitor their use during reading (e.g., Pressley & Afflerbach, 1995). Developing skillful use of these strategies and processes during reading instruction and guided practice may require students to inhibit previously learned habits for reading texts and to implement goal-directed strategy use.

Barkley (1997) proposed that primary weaknesses in inhibitory control lead to secondary difficulties in the executive process of internalized speech. Internalizing speech may be essential to strategic reading comprehension in that students' metacognitive language to themselves helps them regulate their cognitive processes while reading. Given that our study was conducted at only a single point in time, our findings cannot shed light on the development of strategic reading comprehension. They nonetheless raise the possibility that the association between inhibitory control and reading comprehension may be the result of inhibitory control's role in students' prior successes or struggles to learn strategic reading processes. Longitudinal research is much needed to test this hypothesis.

Roles of Attention Shifting in Comprehending Oral Language and Written Text: More Hypotheses

Our second main finding suggests that attention shifting (i.e., the degree to which one can flexibly and efficiently shift from the demands of an old cognitive set or rule to those of a new one) plays multiple roles in reading comprehension. Specifically, attention shifting demonstrated not only a direct, unique association with reading comprehension but also an indirect association with reading comprehension via language comprehension. This indirect association partially mediated the moderately sized relation between attention shifting and reading comprehension. This latter finding suggests that attention shifting could play a role in real-time processing of oral language and in the development of the sophisticated oral language skills necessary for reading fourth-grade texts.

Language comprehension is itself a multifaceted skill, requiring the integration of bottom-up linguistic information (e.g., vocabulary, syntax) and top-down linguistic information (e.g., pragmatic constraints) and world knowledge (e.g., Scarborough, 2001). Applying these at an age-appropriate level in fourth grade likely makes major demands on attention shifting. Although the research on individual differences in EF and language comprehension is somewhat limited, research comparing adults and children in language comprehension suggests that a major difference between the capable adult language user and the less developed child language user lies in the ability to avoid perseveration during online language processing (for a review, see Mazuka, Jincho, & Oishi, 2009).

For instance, Trueswell, Sekerina, Hill, and Logrip (1999) found that 5-year-olds, when listening to syntactically ambiguous sentences, tend to show limited ability to integrate information from pragmatics and to revise their initial interpretations, whereas adults integrated this top-down information quickly and consistently. Specifically, when listening to a simple but initially ambiguous instruction such as "Put the frog on the napkin in the box," young children were only able to perform the correct action 40% of the time, and eye movement data supported the interpretation that children interpreted the napkin as the goal of the action and failed to revise this interpretation after reaching the end of the sentence.

Similarly, Snedeker and Trueswell (2004) found that 5-year-olds, when faced with several ambiguous sentences with different verbs (e.g., told to "Feel the frog with the feather" and given choices between using a feather to feel a frog or touching a frog that was holding a feather) used information about the verbs to disambiguate the sentences but did not use referential information (i.e., were no more successful when shown two frogs, one of which held a feather). To the extent that older students with weaker attention shifting are similar to younger children, these findings suggest that avoiding perseveration in the interest of integrating different sources of information may be essential to skilled language comprehension.

Interestingly, several of the prior studies on EF and reading have treated oral language comprehension skills, particularly vocabulary, as control variables (e.g., Blair & Razza, 2007; Sesma et al., 2009) or matching variables (e.g., Cain, 2006) rather than mediators of the relation between EF and reading. This is in part due to researchers' intention to isolate the effects of EF from other general cognitive abilities, including verbal intelligence, for which vocabulary may be seen as a proxy. Although we agree with this concern, which motivated our use of multiple cognitive skills as controls, we also believe it is important to understand language comprehension as a proximal outcome of EF, not simply a confounding variable. Reframing this relation may be beneficial in future research. In particular, future longitudinal studies are needed to investigate the extent to which EF predicts growth in language comprehension.

Our findings further raise the hypothesis that the role of attention shifting in reading comprehension is not limited to influences on oral language comprehension but extend beyond them. Comprehending written text, as compared with comprehending oral language, makes different demands on and provides different affordances to children (e.g., Duke & Carlisle, 2011). In particular, written text offers the opportunity to shift attention between different elements in the text through such actions as rereading, skimming, and searching for particular information, all guided by a comprehension goal and standards for coherence (e.g., Sticht, 1982). Our findings suggest that attention shifting may facilitate these goal-driven actions and thereby promote successful reading comprehension.

In addition, attention shifting could be implicated in metacognition, a set of controlling processes that Torgesen (1994) and Kuhn (1992), among others, describe explicitly as an executive function. Metacognition, defined by Kuhn as "an executive function that selects, controls, and monitors the use of comprehension strategies" (p. 248), has solid evidence from experimental and developmental research as a key support for text comprehension (e.g., Baker & Brown, 1984; Dole, Duffy, Roehler, & Pearson, 1991; Jacobs & Paris, 1987; Palincsar & Brown, 1984; Pressley et al., 1992; Wagoner, 1983). Shifting attention between textual information and one's own reading strategies as well as flexible use of a variety of reading strategies is likely to be necessary for successful metacognition during reading. In particular, attention shifting may be important to the use of compensatory strategies to overcome limitations in verbal efficiency or other pitfalls (Walczyk, 2000). Future research should investigate the extent to which metacognition mediates the unique relation between attention shifting and reading comprehension.

Implications for Understanding, Preventing, and Addressing Reading Difficulties

Ethnic minority students from low-income backgrounds, like those who participated in the present study, demonstrate elevated risk for reading difficulties (Snow, Burns, & Griffin, 1998). In particular, specific reading comprehension difficulties (i.e., comprehension difficulties in the presence of adequate word reading skills) affect a substantial number of readers in the upper elementary grades and beyond, posing challenges for researchers and educators (e.g., Cain & Oakhill, 2006; Carnegie Council on Advancing Adolescent Literacy, 2010). Addressing these difficulties will require a better understanding of their underlying sources than currently exists. By exploring the relations among EF, language comprehension, and reading comprehension, the current study represents a first step toward building a richer knowledge base that can improve the ways in which we identify and intervene for students at risk for reading comprehension difficulties.

Our findings converge with those of Cutting and colleagues (2009) and Cain (2006) in suggesting that dimensions of EF beyond working memory are important to include in assessment batteries, particularly for students at risk for reading comprehension difficulties. Given evidence for the stability of EF over time (e.g., Willoughby, Wirth, & Blair, 2012), our findings raise the possibility that inhibitory control and attention shifting tasks in early childhood may be valuable in identifying which students are at risk of developing reading comprehension difficulties later, a key hypothesis for future longitudinal research.

Another, compatible hypothesis is that efforts to improve EF in early childhood may have long-term benefits for reading comprehension. Recent randomized controlled trials have shown the efficacy of interventions designed to improve self-regulation and EF for children in preschool and kindergarten (e.g., Barnett et al., 2008; Bierman et al., 2008; Diamond, Barnett, Thomas, & Munro, 2007; Raver et al., 2011). This evidence suggests that early intervention efforts could benefit from incorporating strategies to support the development of EF and self-regulation. Long-term intervention research will be necessary to determine whether such early intervention efforts can facilitate the development of EF in ways that prevent later reading comprehension difficulties. Given the need to attend to young children's language comprehension and emergent literacy development as well as their EF development (e.g., Snow et al., 1998), we recommend that such research should investigate ways to integrate these domains rather than studying them in isolation.

At the same time, later intervention efforts may also benefit from taking into account the co-occurrence of EF weaknesses and reading comprehension problems. In particular, interventions for struggling older readers may need to plan instruction in ways that provide access to students whose EF weaknesses will otherwise prevent them from benefitting from instruction. For instance, structuring classroom environments to help students regulate their attention during instruction could be essential to the success of reading comprehension interventions. In addition, such interventions may need to find ways to provide compensatory strategies to students who struggle with EF. In this way, the EF weaknesses of struggling comprehenders in the upper elementary grades and beyond may need to be viewed not as targets for specific interventions but rather as important constraints to consider when designing interventions that target various reading domains, such as comprehension strategies and vocabulary.

Limitations and Future Research

One result that we found surprising in light of past research was that the measure of working memory was only weakly correlated with other skills and did not uniquely predict word reading or reading comprehension in the path analysis model. Given past evidence for the importance of working memory to reading and our limited statistical power to detect small effects, we hesitate to interpret this null result. One possibility is that it may be specific to the visual matrix measure used. This measure has the advantage of being parallel to the attention shifting and inhibitory control measures in the use of nonverbal stimuli. However, a related disadvantage is that it might not have captured the aspects of updating verbal information in working memory that are most important to reading, given evidence that spatial and verbal working memory tasks each predict their own domain much more strongly than the other domain (e.g., Shah & Miyake, 1996). Future research should investigate the unique contributions of attention shifting and inhibitory control, after controlling for other working memory tasks. Ideally, research on EF and reading would utilize multiple measures of each dimension of EF.

This study has some additional limitations to be noted and addressed in future research. First and foremost, unlike some of the high-quality work with young children (e.g., Blair & Razza, 2007; Welsh et al., 2010), the current study only investigated these relations at one point in time. Longitudinal research, particularly studies that follow students beyond the primary grades, will be needed to shed greater light on the role of EF in growth in reading comprehension and its component skills. Second, the study's correlational design prevents us from making causal inferences and raises the need for experimental intervention studies. Third, although we made several efforts to address the effects of our sample size (see the Appendix), it nonetheless provided relatively limited statistical power to detect small effects. As such, we emphasize the statistically significant results and encourage readers to interpret the null results reported with caution.

Relatedly, although we found no differences between native English speakers and second-language learners in the relations of interest, we do not emphasize these null results because of insufficient statistical power to detect small differences between these groups. Future research that collects data on larger samples of second-language learners and native English speakers is needed to investigate differences by language background. Finally, although our measure of attention shifting, the Wisconsin Card Sorting Test, is frequently used in research in this area, it is a complex measure that also draws on working memory and inhibitory control to some extent, a problem of measurement impurity that is common in EF studies. Additional measurement development and validation work will be needed to advance research on EF and academic outcomes.

Conclusion

In this study, we found evidence for the roles of attention shifting and inhibitory control in reading comprehension during middle childhood. Our findings suggest that both inhibitory control and attention shifting may be important for successful comprehension of text but that the mechanisms by which they influence comprehension may differ. Specifically, both attention shifting and inhibitory control directly predict reading comprehension above and beyond word reading and language comprehension, while attention shifting may also be important in language comprehension. Our findings highlight the importance of investigating a variety of EF dimensions as we seek to build a more complete model of reading comprehension and to inform efforts to address reading comprehension difficulties.

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APPENDIX

Assessing Small-Sample Bias and Power

As mentioned in the main text, fitting path analyses to relatively small samples has the potential to introduce bias into parameter estimates and standard errors (in addition to introducing bias into goodness-of-fit statistics, which we addressed with the Swain correction discussed previously). To assess the extent of this bias with our sample size of 120 participants and our hypothesized model, we conducted a post hoc Monte Carlo simulation. Specifically, we specified the magnitudes of the population parameters based on the results from the full model in Table 3, which are the best available estimates of what these parameters might be, and we conducted 10,000 replications.

Following Muthén and Muthén (2002), we then evaluated the bias for each parameter in the model by comparing the parameter estimate average over the replications to the specified population parameter. We found that the greatest bias in any parameter was 6.7%, with most parameters demonstrating bias below 1%, thus meeting Muthén and Muthén's standard of less than 10% bias in any parameter. To assess standard error bias, we compared the standard deviation of each parameter estimate over the replications (which is taken as the population standard error when number of replications is large) to the average of the estimated standard errors for each parameter estimate. We found that the greatest bias in any standard error was 4.6%, thus meeting Muthén and Muthén's standard of less than 10% bias in any standard error and less than 5% bias in the standard errors for the relations of interest. We thereby conclude that there is little reason to suspect bias because of small sample size in either the parameter estimates or the standard errors.

In addition, small sample sizes can limit statistical power in path analyses, as in other types of statistical analyses. We used the Monte Carlo simulation described previously to assess the statistical power for the relations of interest by examining the percentage of parameter estimates across the replications that were significant (Muthén & Muthén, 2002). We found that our design yielded power approaching .80 to detect standardized regression coefficients of approximately .19 (i.e., the magnitude of the direct relation between inhibitory control and reading comprehension), power above .50 to detect standardized regression coefficients of approximately .16 (i.e., the magnitude of the direct relation between attention shifting and reading comprehension), and power below .50 to detect smaller effect sizes (i.e., the magnitudes of the relation of inhibitory control and attention shifting with word reading and the relation between inhibitory control and language comprehension). This indicates that our hypothesized model and sample size yielded adequate statistical power to detect small to moderate associations but not small associations.