THE RELATION BETWEEN COGNITIVE SKILLS AND LANGUAGE SKILLS IN
TYPICALLY-DEVELOPING 3 ½ -TO-6 YEAR OLDS

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by

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ABSTRACT

Some prior research has examined how cognitive components contribute to young children’s progress in language acquisition, but the majority of these studies have focused on a specific component such as phonological short term working memory and how it relates to either concurrent vocabulary levels or vocabulary learning. The present study is the first to ask how multiple information processing components, including phonological short term working memory, and executive functions (EF) including inhibitory control processes, speeded processing, planning, goal setting and management, goal-directed search and retrieval, monitoring, shifting, coordination, and attentional flexibility pattern together in their contributions to children’s language. Furthermore, the current study examines how these varied cognitive components differentially contribute to vocabulary, syntax, and narrative domains in children between the ages of 3½ and 6 years. Results reveal that children’s narrative production and comprehension are best predicted by the most complex EF tasks which recruit attentional flexibility, executive goal management, monitoring, coordination, and inhibitory control, along with simple EF tasks which require planning. Syntax production is best predicted by phonological working memory, as well as a set of simple EF skills including updating and monitoring, and inhibition, and complex EF skills including attentional flexibility, shifting, and coordination. Syntax comprehension, in contrast, is only supported by simple EF planning, updating and monitoring skills, and the complex EF skills underlying card sorting and switching performance. And finally, vocabulary comprehension and production is best predicted by a set of simple EF skills including goal-setting, inhibition, planning, and updating and monitoring. Overall, our results reveal the dynamic recruitment and coordination of more and more EF functions as the domains of language shift from vocabulary, to simple syntax, to complex syntax,
to narrative. Implications are discussed including possible refinement in theories of language acquisition as well as in strategies for children's language remediation to better accommodate the important roles of a broad range of cognitive functions that develop at different rates in different children.
# Table of Contents

List of Tables .............................................................................................................vi  
Acknowledgements ....................................................................................................vii

Chapter 1. INTRODUCTION......................................................................................... 1  
  Theoretical Framework............................................................................................5  
  Prior Studies Examining Individual Cognitive Predictors of Language...............6  
  Summary of Findings of Multiple Information Processing Skills and Language……34  
  Current Study.........................................................................................................35

Chapter 2. METHOD.....................................................................................................38  
  Participants. ........................................................................................................38  
  Measures ............................................................................................................38  
  Procedure...........................................................................................................47

Chapter 3. RESULTS..................................................................................................48

Chapter 4. DISCUSSION.............................................................................................56  
  Cognitive Skills and Narrative Discussion...........................................................56  
  Cognitive Skills and Syntax Discussion...............................................................63  
  Cognitive Skills and Simple vs. Complex Syntax Discussion.............................69  
  Cognitive Skills and Vocabulary Discussion......................................................75  
  General Discussion...............................................................................................79  
  Conclusions.........................................................................................................84

References................................................................................................................91

Appendix ..................................................................................................................107
List of Tables

Table 1. Results of multiple regression analysis with narrative production as the outcome variable. .................................................................48

Table 2. Results of multiple regression analysis with narrative comprehension as the outcome variable. .................................................................49

Table 3. Results of multiple regression analysis with syntax production as the outcome variable. .................................................................50

Table 4. Results of multiple regression analysis with syntax comprehension as the outcome variable. .................................................................51

Table 5. Results of multiple regression analysis with syntactic production for simple structures as the outcome variable. .................................................................52

Table 6. Results of multiple regression analysis with syntactic production of more complex structures as the outcome variable. .................................................................53

Table 7. Results of multiple regression analysis with syntax comprehension on simple structures as the outcome variable. .................................................................53

Table 8. Results of multiple regression analysis with syntax comprehension on complex structures as the outcome variable. .................................................................54

Table 9. Results of multiple regression analysis with vocabulary production as the outcome variable. .................................................................55

Table 10. Results of multiple regression analysis with receptive vocabulary as the outcome variable. .................................................................55
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The Relation between Cognitive skills and Language Skills in Typically-Developing 3 ½-to-6 Year Olds

Language acquisition is a universal phenomenon that unfolds in a relatively predictable manner. Across all cultures, children demonstrate fairly consistent developmental milestones in the acquisition of their native language. These milestones typically include an initial stage of babbling, repetition of common consonant vowel combinations, one-word utterances, a multi-word stage and the gradual acquisition of increasingly complex grammatical structures and increasingly complex narrative or story structures. The emergence of these forms of language usually occurs within modestly constrained developmental windows unless there are significant cognitive, neurological, and environmental risks impacting the acquisition process. It should be noted, however, that similar to other human skills, language development does not occur in an identical manner for every child. There are substantial variations for vocabulary, syntax, and narrative, in both the rate of acquisition, as well as the skill and proficiency levels ultimately attained by individuals.

Developmental language research has focused on two main areas of inquiry – an investigation into the typical developmental stages of language acquisition and the study of the characteristics of children who do not acquire language at the same rate or proficiency as their typically developing peers. The latter line of research has relied mostly on an examination of children diagnosed with Specific Language Impairment (SLI) as this has allowed researchers to investigate the factors that result in lower levels of expressive and receptive language ability in the absence of confounding factors such as low intelligence and obvious neurological deficits.
The study of children with SLI has allowed researchers to further test theories of language learning and how, or whether, the cognitive system interacts with the language system during development. Proponents of certain nativist models of language learning (e.g. Pinker, 1991) argue that language develops in a modular manner independent of other skills and cognitive abilities. Children with SLI have been taken as evidence for this perspective, as their language impairment is attributed to a malfunctioning “grammar module” in the brain. In contrast to this modular theory of language development, connectionist accounts (Elman, Bates, Johnson, & Karmiloff-Smith, 1996; Seidenberg, 1997) and dynamic systems accounts (Nelson, Craven, Xuan, & Arkenberg, 2004; Thelen & Smith, 2006) of language development posit that language emerges from complex interactions between biological factors and exposure to language via specific features of the conversational environment. As one example, the finding that children with SLI show impairments in non-linguistic processing as well as linguistic processing has been used to argue for there being a general cognitive deficit instead of an abnormally developing language-specific module in these children. More specifically, children with SLI have been shown to perform slower on motor and cognitive tasks such as mental rotation tasks that do not require language (for e.g., Kail, 1994) compared to typically developing peers; a finding that is incompatible with the idea that language develops independently of domain general cognitive skills. Evidence such as this undermines the credibility of modular accounts of language learning and demonstrates that the cognitive system may indeed have links with the developing language system.

The developmental literature on how the cognitive system possibly interacts with the language system in children with SLI may also be potentially informative for how these skills interact in typically developing children. In fact, it has been argued by Leonard (1998) that
children with so-called “Specific” Language Impairment might not actually suffer from a unique language-bound disorder, but instead may represent a lower information-processing-ability profile on the same continuum as typically developing children.

Indeed, there is increasing empirical support for certain cognitive, or information-processing skills, such as short term working memory and processing speed, being implicated in the language acquisition and performance of typically developing young children (e.g. Leonard et al., 2007; Gathercole, 2006). However, the current literature on how cognitive resources are related to emerging language skills is considerably divided at this point. In some cases, studies with young children have shown that having greater working memory capacity available for processing of information is a strong predictor of greater vocabulary and grammatical learning (French & O’Brien, 2008; Gathercole, 2006; Service, 1992). Other studies fail to show a significant relationship between working memory span and sentence comprehension in children between the ages of 3 ½ and 6 years (de Abreu, Gathercole & Martin, 2011; Willis & Gathercole, 2001). Furthermore, some cognitive skills have failed to receive much attention in the cognitive developmental literature in terms of how they relate to emerging language abilities. For example, processing speed has only been studied in relation to language abilities in school-aged children, and no empirical investigations to date have been conducted looking at the differential links between processing speed and vocabulary relative to syntax or narrative abilities in preschoolers. And finally, there is very limited research looking at how the multiple aspects of executive function (EF) including retrieval processes, speeded processing, inhibitory control, goal management, monitoring, planning, updating, integration, and attentional flexibility relate to language abilities in preschoolers.
The cumulative body of research to date on how cognitive skills relate to emerging language skills (reviewed in detail later in this paper) has helped identify some of the possible information processing components that are influential in children’s language acquisition, but most of this work has looked at these components in isolation. Many individual variables have been implicated in more successful performance and acquisition, but the current study seeks for the first time to take advantage of a fuller and more integrated approach in which fairly rich cognitive profiles can be tied to individual differences in young children’s ongoing progress in language acquisition. Multiple information processing components will therefore be assessed and related to vocabulary, narrative, and syntax outcomes, which will also be measured in a more refined and comprehensive manner.

The goal of the current study will be to examine how multiple cognitive skills including phonological short term working memory and Executive Function (EF) abilities as tapped by 7 differentiated EF tasks relate to emerging production and comprehension in the domains of vocabulary, syntax and narrative in young children between the ages of 3 ½ and 6 years. The current study also seeks to distinguish the contributions made by 5 relatively simple EF tasks and 2 more complex EF tasks in performance across the different language domains. It is hypothesized that only greater phonological short term working memory will be significantly related to superior vocabulary skills, but that superior emerging syntax and narrative skills will be related to a more complex profile of cognitive skills including multiple EF processes. Particularly for complex syntax and for narratives –which by their nature require coordination across sequences of vocabulary, syntax, and narrative structures–it is predicted that the combinations of EF cognitive functions tapped by both simple EF tasks and complex EF tasks will be important contributors to children's language progress.
Theoretical Framework

The emergentist perspective of language development that includes, and builds upon, dynamic systems theory and connectionism is based on the assumption that language emerges from a complex interaction between the neuronal system and the environment, and focuses on understanding the mechanisms by which language emerges from more domain-general processes (Elman, 2003; McClune, 2008). These theorists view language as being “softly assembled,” with children’s general capacities for processing and perceiving speech and pattern abstraction abilities providing constraints on how input from the environment is processed (Evans, 2001; Marchman, 1997). Language acquisition is theorized to emerge from interaction between the child and the environment as the child integrates the various acoustic, linguistic and social/pragmatic cues within the context of ongoing communicative interactions (see Competition Model by MacWhinney, 2005). According to multiple emergenist theories and dynamic systems theories, the ways in which the child learns from ongoing conversations depend also upon the memory, perceptual pattern abstraction, retrieval, and planning resources the developing child has available.

The interplay between cognitive and language structures is also supported by a dynamic systems framework. In accordance with a dynamic systems perspective, when learning new vocabulary, syntax, or narrative, it has been argued that "numerous social, emotional, motivational, cognitive, structural challenges and current neural network conditions must reach threshold levels of convergence to support any advances in learning" (Nelson, 2000; Nelson & Arkenberg, 2008). These authors argue that while it is possible to identify and isolate individual components contributing to acquisition, it is also important to understand how multiple conditions cooperate and converge to support advances in learning. Individual differences in
learning across individuals are attributed to differences in the individual components and in how the dynamic convergences between components occur during various episodes of learning (e.g. Nelson, 1987; Nelson, 2000; Nelson et al., 2004; Nelson & Arkenberg, 2008).

Smith and Thelen (2003) also argue that development can be seen as “a series of evolving and dissolving patterns of varying dynamic stability, rather than an inevitable march towards maturity.” One of the fundamental principles of dynamic systems theory is multicausality, or the idea that the complex system of behavioral development is driven by “many individual elements embedded within, and open to, a complex environment” and that these elements become self-organized over developmental time (Thelen & Smith, 2006). Using this perspective, different behavioral modes are viewed as “attractor states,” that push an individual to prefer one behavior over another at any point in time. There are, however, limitations that help determine what a preferred attractor state will be, or what new attractor states will develop. A child’s current limits on working memory capacity, processing rates, and complex goal management might constrain the system from attaining attractor states associated with rapidly processing complex sentence structures, for example.

Prior Studies Examining Individual Cognitive Predictors of Language

Working memory and language.

Working memory refers to the ability to temporarily store and manipulate information in an online manner in the course of other ongoing cognitive activity (Baddely, 2000; Daneman & Carpenter, 1983). It has been theorized by some psycholinguists that one of the primary roles of working memory is to support language acquisition, especially given the heavy involvement of sequence learning in acquiring linguistic structures (e.g. Ellis & Sinclair, 1996; Daneman &
Carpenter, 1980). Both vocabulary and syntax acquisition involve sequence learning, as learning vocabulary involves sequence learning of phonological properties of words including syllable and phonotactic structure, and syntax learning involves sequencing of lexical units and sequential coordination of multiple syntactic rules. Narrative abilities also crucially depend on working memory resources as they require sequencing of events in working memory, keeping causal relationships across various episodes in mind, extracting meaning for each sentence as it occurs, as well as the activation and use of a story schema (Stein & Glenn, 1979; Stein & Albro, 1997) to help guide the narration of events. It is not surprising therefore that working memory in some studies has been a predictor of vocabulary size and has also been shown to be related to the comprehension of syntactically complex sentences and narrative abilities in young children. The following section will look at the details of work in this area, giving primary attention to studies of children during the period of rapid language growth between 3 ½ and 6 years of age.

**Short term working memory and language.**

A specific aspect of short term working memory, i.e. phonological working memory has been particularly associated with children’s concurrent vocabulary knowledge (Gathercole, Willis, Emslie & Baddeley, 1992), and this type of working memory also been shown to be a predictor sometimes of vocabulary acquisition in both a child’s native language (Gathercole & Baddeley, 1990) as well as in foreign language learning contexts (Cheung, 1996; French & O’Brien, 2008).

Phonological working memory is typically assessed using a nonword repetition task. In this task, children are presented with sets of nonwords ranging in length from one, to four or five, syllables. According to Gathercole (2006), this nonword repetition task does a more accurate job
of assessing the phonological short term store (of Baddeley’s (1986) model of the phonological loop) compared to serial recall tasks that involve recalling a sequence of digit names or other short familiar words. This claim is based on the idea that the lexical nature of word stimuli used in serial recall tasks also necessarily implicates activated lexical representations which can be used to reconstruct incomplete phonological representations held in the phonological storage space at the point of retrieval. The use of nonwords as stimuli potentially circumvents this issue and may provide a purer assessment of phonological storage quality because lexically-based reconstruction processes cannot compensate for deficits in basic phonological storage capacity in this case. The current study will utilize both kinds of measures, forward digit span and nonword repetition, to see if any differences emerge in how these tasks relate to language outcomes.

It has further been theorized that this phonological storage capacity plays a key role in the learning of the sound structure of novel words during vocabulary acquisition (Baddeley, Gathercole & Papagno, 1998). More specifically, it is theorized that initial encounters with the novel word will result in the sound structure of the word being represented in the short term phonological storage space. This representation is then speculated to be used to abstract a more complete and stable specification of the sound structure of the word across repeated occurrences. Conditions that may affect the quality of this phonological representation in the short term storage space will in turn affect the process of abstraction and learning rates of novel words. One constraint on the quality of this representation is the amount of storage space itself that is available to the individual.

There is a growing body of empirical support for this mechanism, as associations have been identified between children’s phonological memory and their vocabulary knowledge.
(Gathercole et al., 1992), with better phonological memory being associated with better vocabulary knowledge.

A specific link has been demonstrated between phonological memory skills, as assessed by both nonword repetition and digit span tasks, and vocabulary knowledge in typically developing 4 to 5 year olds (Adams, Bourke & Willis, 1999). In this study, a significant amount of variance (10%) in vocabulary knowledge was found to be explained by phonological memory skills (a composite score was used for both tasks) after controlling for age, non-verbal ability and visual memory.

This result has also been replicated in 6 year old bilingual children speaking Luxembourgish and German (de Abreu et al., 2011). Verbal short term memory assessed using a digit span task was found to make unique contributions to vocabulary acquisition accounting for 28% of variance, and this association was found to be independent of cognitive control, fluid intelligence and rhyme awareness in these children.

Links have also been demonstrated between children’s phonological memory and multiple expressive language skills including length of spontaneous utterances and repetition of sentences of varying complexity (Blake, Austin, Canon, Lisus, & Vaughan, 1994), and it has proven possible to differentiate the spoken language profiles of young children at ages 4 and 5 years grouped in terms of their phonological memory skills (Adams & Gathercole, 1995).

An important qualification that has been made in literature on how phonological working memory abilities relate to language acquisition is that this link between phonological working memory and vocabulary seems to only be reliably present in the early stages of language learning. Gathercole et al. (1992) found this relationship to be the most salient between the ages
of 4 and 6 years, with the association being the strongest at 4 years of age and declining by 8 years in a longitudinal cohort of typically developing children. The authors accounted for this finding by suggesting that phonological learning of new words in middle childhood may be supported by other factors such as exposure to print that may overshadow the influence of the phonological loop in word learning. However, further explanations may be in order given that in the work of Gathercole and colleagues there are both inconsistent findings at particular ages, along with a decline across age in the modal degree of correlation across studies, ranging from about $r = .28$ to $.49$ at age 4, to $r = .20$ (ns) to $.34$ at age 5, and $r = .22$ (ns) to $.23$ (ns) at age 8.

One contention that has been raised regarding the association between nonword repetition measures and vocabulary is that this association may not be purely driven by a phonological storage capacity account, but rather this phonological working memory measure may have some overlap with general phonological processing abilities such as a phonological sensitivity (Bowey, 2001). Gathercole (2006) also concede that their data are not able to tease apart contributions made by the storage aspect from those arising from more general phonological processing abilities. Only one longitudinal study to date has found that phonological working memory as assessed by a nonword repetition task at age 5 (only when it was leniently scored) maintained predictive ability for vocabulary skills at age 6 after controlling for phonological sensitivity (Bowey, 2001). However, the author still maintains that the “association between nonword repetition and vocabulary in young children may, to a substantial extent, reflect a latent phonological processing ability that is also manifest in phonological sensitivity (Bowey, 2001, p. 441).”

Interestingly, there is some empirical evidence indicating that lexical growth can also facilitate phonological re-organization (in terms of lexical-phonological, semantic and
conceptual complexity), which can in turn enhance the quality of phonological representations used to encode and store verbal information in the phonological storage space. Multiple studies have found that receptive vocabulary at age 5 predict nonword repetition scores at age 6 and 8 after controlling for age and autoregressive effects (Gathercole, Pickering, Ambridge & Wearing 2004; Bowey, 2001), and these findings support the idea that there are reciprocal interactions between phonological processing abilities and vocabulary (see also, Nelson, Welsh, Vance Trup & Greenberg, 2011).

In addition to findings showing significant links between phonological processing skills and native language skills, nonword repetition scores have also been shown to be significantly correlated with foreign language skills in elementary school aged children between the ages of 8 and 10 years. Masoura and Gathercole (1999) found that nonword repetition was significantly associated with foreign language knowledge even when the effects of native language knowledge were partialled out. However, it should be noted that the same was not the case for the association between nonword repetition and native language knowledge, which became non-significant when the effects of foreign language knowledge were controlled for. This tentatively suggests that foreign language learning in middle childhood may rely more heavily on the phonological processing system compared to native language development.

Whereas the link between phonological working memory and vocabulary is modestly consistent across studies, there is less evidence for links between phonological working memory and syntax. It has been theoretically argued that phonological working memory may also play an important role in children’s grammatical and morphological learning (Nelson, 1987; Plunkett & Marchman, 1993; Speidel, 1993), as it is reasoned that higher working memory resources would allow for the maintenance of various possible parses active in parallel, as well as the rehearsal of
words and phrases which should in turn assist in sentence processing and learning. Indeed, there is some evidence showing that 3 and 4 year olds with higher phonological working memory produce longer utterances, more varied and complex syntactic constructions in spontaneous speech (Adams & Gathercole, 1995, 2000; Willis & Gathercole, 2001). In a separate study, word span (as assessed by a familiar word recall task) was found to predict sentence imitation scores across the whole preschool age range (Blake et al., 1994). Importantly, word span also predicted mean length of utterance in spontaneous speech elicited from the younger preschool children between the ages of 2-3 years better than chronological age or mental age.

Research reporting mixed evidence for a link between working memory and syntactic abilities include a study conducted by Willis and Gathercole (2001) in which repetition but not comprehension of complex sentences was related to phonological working memory in 4 to 5 year olds. The authors use the conceptual argument raised by Martin and colleagues (see Hanten & Martin, 2000; Martin, Lesch, & Bartha, 1999) to account for their result by suggesting that processing resources may be differentially recruited by receptive and productive tasks, and that temporary phonological representations and conceptual representations may be relied on more heavily to support sentence repetition performance, whereas sentence comprehension may depend more directly on access to temporary semantic representations.

A study by de Abreu and colleagues (2011) also showed significant associations between verbal short term memory (assessed by both non word repetition and digit span tasks) and syntax in 6 year old bilingual children. However, this relationship was mediated by vocabulary, and the association was non-significant once vocabulary abilities were controlled. It should be noted that this is a rare study that examined the differential associations between different cognitive skills and language abilities, including phonological working memory, cognitive control abilities and
vocabulary and syntax skills. More research is needed of this kind in which multiple cognitive and language abilities are examined together rather than just reports of correlations of single variables to syntax levels or vocabulary levels.

Differential patterns of association between phonological working memory skills and sentence comprehension have also been found for language disordered vs. typically developing groups of children. Montgomery and Evans (2009) found that non word repetition was significantly correlated with simple sentence comprehension, but not with complex sentence comprehension in 6-12 year old children (mean age= 9 years; mean language age= 6 years) with SLI. This relationship was not found for the typically developing controls. It should be noted that complex sentence comprehension was associated with a competing language processing task (referred to as an attentional resource allocation task) for both children with SLI and language matched controls, but not for age matched controls. Thus, at least for the language disordered group, both simple and complex versions of the sentence comprehension tasks did seem to tap into their executive control abilities to a greater extent compared to their typically developing peers. However, unexpectedly, phonological memory skills were related to processing of relatively simpler sentences in children with SLI and this processing resource did not appear to be significantly implicated in the comprehension of complex sentences. It should be noted however, that the complex sentences used in this study were no longer than 8 words and did not contain multiple embeddings. Thus, it is possible that phonological working memory would have been recruited for the processing of more complex sentences in these children.

Second language learning studies have also implicated phonological working memory as a significant baseline predictor of grammatical learning in young children (French & O’Brien, 2008; Service, 1992). French and O’Brien (2008) found that phonological memory skills
measured on entry into the study in native-French speaking 11-year-olds accounted for at least 27.9% of significant variance in grammar skill five months into an intensive English language program after taking into account L2 contact, nonverbal ability, earlier grammar skill, and most importantly, vocabulary knowledge.

The links between phonological memory and acquisition of grammatical structures in the L2 have not consistently been observed however. A study conducted on younger children by Service & Kohonen (1995) did not reveal a comparably strong relationship between working memory and second language learning. Although nonword repetition was found to be correlated significantly with Finnish speaking elementary children’s scores on tests of English grammar and fluency, this relationship was found to be mediated by English (L2) vocabulary.

Conceptually, it has been argued mainly by connectionist theorists that grammatical learning is very similar to vocabulary learning (Ellis, 1996; Ellis & Sinclair, 1996). As mentioned previously, both involve sequencing of structures; either the sequencing of phonemes within words or morphemes within syntactic phrases. In both cases, the actual sequencing of structures is believed to be processed in phonological short term memory. The initial stages of learning are believed to more heavily involve phonological memory for both vocabulary (which has considerable empirical support), but also for syntax (which has growing support) as learners use phonological storage as a means to establish long-term representations of the items. However, according to Williams and Lovatt (2003), the generalization of new sequences of familiar grammatical items may also be related to phonological memory. This proposal is based on their work with adults learning artificial grammar showing that phonological short term memory correlated better with the rate of learning (as assessed by grammatical generalization scores) than with ultimate attainment levels. According to this conceptual framework,
phonological memory would be recruited in later stages of proficiency once familiarity with the structures increased as well (unlike the limited initial involvement of phonological memory in vocabulary learning) to help learners use these newly acquired grammatical structures accurately across multiple contexts.

The current study seeks to compare the differential associations between phonological working memory and multiple other cognitive components to syntactic structures of ranging complexity to identify patterns of contributing cognitive components for simpler versus more complex sentence production and sentence comprehension.

Very little research has been conducted on the link between phonological working memory and narrative abilities in young children. Dodwell and Bavin (2008) conducted a study that examined how working memory abilities related to narrative abilities in 6-7 year old children, including a subset of typically developing children and children diagnosed with SLI. Word span (using highly familiar words) was related to story recall ($r = .45$) and comprehension ($r = .32$) on a story eliciting task—a standardized task in which the child generated their own story from a picture book and then was asked to recall as much information as possible and answer some comprehension questions. Significant associations were not found between word span and story recall and comprehension on a standardized story re-telling task however. An inconsistency was also observed across the two phonological working memory tasks used, as digit span was not related to performance on either of these narrative tasks. It should also be noted that although word span appeared to be modestly correlated with performance on a story telling task, it did not account for any unique variance in story comprehension or recall performance. The relatively small sample size ($N=42$) may have reduced the power of the study.
to detect effects of working memory on narrative. It also remains unclear whether these patterns would be different at younger ages.

It is helpful to summarize the developmental associations found between phonological working memory and children’s language skills in various domains. For lexical skills, there is modest but not entirely consistent evidence that phonological working memory as assessed by digit span and/or non word repetition tasks is positively related to concurrent vocabulary skills in the 3½ -6 year age range. For studies demonstrating this relationship, typical bivariate correlations range considerably from $r = .28$ to $.49$.

The findings for a link between phonological working memory and syntax skills in young children at ages 3½ to 6 years are more mixed in comparison. Word span (using familiar words rather than nonwords) was found to predict unique variance (15%) in sentence imitation skills of children between the ages of 2-5 years; however, this measure of word span failed to predict spontaneous productive syntax (as measured by mean length of utterances) in the 4 year olds in this sample (Blake et al.,2004). It is interesting to note that for the younger 2-3 year olds, word span not only predicted spontaneous speech complexity, but it was a stronger predictor than chronological age or mental age. This finding potentially lends support to the idea that speech production in the very early stages of language acquisition, when certain grammatical forms are still being acquired, may draw more strongly on phonological memory using it as a response buffer to support articulation (Adams & Gathercole, 1995); this being in contrast with more controlled processes supporting proficient or advanced language abilities. Differential associations have also been found between phonological working memory and sentence repetition compared to sentence comprehension in 4-5 year olds; with phonological working memory being related to the repetition, but not comprehension, of complex sentences (Willis &
Gathercole, 2011). It is likely, given these results that sentence comprehension and repetition rely on different sets of cognitive resources, with comprehension being more constrained by processing at the syntactic and conceptual level rather than at the phonological level. Finally, the extent to which vocabulary may mediate this link between phonological working memory and syntax has not been explored extensively at younger ages, though there is some evidence that when vocabulary levels are controlled, phonological working memory is no longer related to syntax abilities in 6 years olds (de Abreu et al., 2011). Overall then, new and more systematic studies are needed to determine how much phonological working memory contributes to syntax progress during the 3 ½ to 6 year age range.

Finally, the extent to which phonological working memory supports children’s narrative comprehension or production acquisition has received shockingly little attention in the literature. There is some evidence from a single study that suggests phonological working memory, as assessed by a word span task, may be related to narrative comprehension in 6-7 year olds. It remains unclear whether this pattern of phonological memory-to-narrative abilities would replicate when other predictors are included in research or whether it would hold at younger ages.

**Processing speed and language.**

One theoretical motivation for including processing speed (or sometimes in the literature, “speeded processing”) ability in the battery of information processing resources that may help support acquisition of vocabulary and syntax in early childhood is based on Just and Carpenter’s (1992) conceptual work suggesting that as children acquire language, processing limitations can result in incomplete processing of words and syntactic structures that appear in the speech
stream. Similar emphases upon the limits that slow processing speed may place upon complex language and literacy acquisition have been made by other theorists as well, including: Case & Okamoto (1996) in their discussion of information processing constraints on the development of narrative skills, Nelson and colleagues (2004; 2008; 2001) in their discussion of mixes of conditions that support language learning, and Wolf and Bowers (1999) in their discussion of the contributing role of processing speed to reading fluency.

Processing speed relates to the speed or efficiency with which information can be processed (Kail & Salthouse, 1994). This construct is not unrelated to either working memory or to aspects of executive function, as faster speed can allow faster rehearsal/retrieval/integration of information, which in turn can result in greater amounts of information being stored in working memory and faster and more complex manipulations of information in working memory. There are only a small number of studies at any age level in which processing speed has been investigated in relation to language outcomes.

In a study conducted by Leonard, Ellis Weismer, Miller, Francis, Tomblin and Kail (2007) with 14 year old children including a subset of children with language impairment and a subset of typically developing controls, processing speed was found to have important contributions to language outcomes across the entire sample. Both a nonverbal cognitive speed factor (assessed by a timed visual search task, mental rotation task, and picture naming task) and a general speed of processing factor (including both linguistic and non-linguistic speed tasks) in separate models emerged as important factors that contributed to the models accounting for a significant amount of variance in a language composite score. In this study, the language composite score was calculated using an extensive battery of language measures that included receptive and expressive vocabulary and syntax assessments as well as narrative comprehension
and production measures. It remains an empirical question as to whether processing speed has
differential associations with the different domains of language and whether cognitive speed
measures are important predictors of language levels in younger children in the 3 ½ to 6 year
age-period.

One study that addresses this issue of differential associations with different types of
language tasks is a study conducted by Montgomery and Windsor (2007) with school-aged
children (6-11 year olds). These researchers found that processing speed ability (as assessed by
an auditory detection reaction time task) related to offline language performance (as assessed by
standardized language measures testing sentence comprehension and production) through
associations with phonological working memory, but related directly to an online language
processing task (a word recognition task). This online language processing task required children
to press a button response as quickly as possible once they heard a target word in a short two-
sentence paragraph. Target words were presented prior to the onset of each trial. The authors
attribute this differential association of processing speed abilities to an online vs. offline
language task to familiarity effects, and suggest that speed may be more strongly associated with
the processing of familiar language materials (i.e. lexical content and material) compared to less
familiar language material/ content on standardized language measures.

In a separate study, Montgomery, Magimairaj, and O’Malley (2008) examined the
contributions of processing speed abilities to the comprehension of simple versus complex
sentences in school-aged children. Differential associations were found between processing
speed and comprehension of the two types of syntactic constructions, as substantial variance
(6.7%) was only accounted for in the case of complex sentence comprehension by the processing
speed abilities of 6-12 year olds.
A rare study that has examined multiple information processing skills and how they relate to narrative performance in young children was conducted by Montgomery, Polunenko and Marinellie in 2009. They included processing speed abilities (as indexed by auditory visual reaction times) in their battery of predictors and found that it correlated significantly ($r = .30$) with narrative comprehension (assessed by a series of prompted comprehension questions regarding stories from a standardized narrative measure) in 6-11 year olds. Additionally, after accounting for age, processing speed accounted for a significant 5.2% of variance in narrative comprehension abilities. These results are consistent with theoretical predictions that narrative comprehension would draw substantially on processing resources due to the high demands on rapid processing and integration of information in a story-listening context. It is as yet unclear as to whether processing resources for narrative are tapped to an equivalent or larger extent at younger ages.

In summary, processing speed abilities have been associated with global language abilities (Leonard et al., 2007), and there is some evidence that processing speed may support online word recognition (Montgomery & Windsor, 2007) and the processing of complex syntactic structures (Montgomery et al., 2008) and narrative comprehension (Montgomery et al., 2009) in school age children. No study to date has examined the differential contributions of processing speed to vocabulary, syntax, and narrative comprehension and/or production in younger children in the preschool period though. The current study will address this gap in the literature by including processing speed as one Simple EF (cf. Welsh, Pennington, & Groisser, 1991) examined in relation to vocabulary, syntax abilities and narrative skills in 3 ½ to 6 year olds.
Central executive functions and language.

Executive functioning has mostly been studied in relation to adult cognitive functioning, but results from both neuropsychological and cognitive developmental research converge to suggest that EF refers to tasks or behaviors that are sensitive to prefrontal dysfunction. These tasks involve goal-directed behavior, or the “appropriate set maintenance to achieve a future goal” (Welsh et al., 1991, p. 132). In order to achieve this future-directed or goal-directed behavior, individuals engage in selective attention and retrieval, planning and programmatic behavior, hold these plans or programs online until execution, integrate information, edit and monitor these plans, and inhibit irrelevant or distracting information. According to Miyake, Friedman, Emerson, Witzki & Howarter (2000), three key functions underlying executive functioning include mental set shifting, information updating and monitoring, and inhibition of prepotent responses. Baddeley’s (2000) revised working memory model also includes executive functioning as a critical element, and an attentional control system (termed the “central executive”) is said to be responsible for allocating attention resources to different cognitive processes. Attentional control does seem to be a key cognitive ability that overlaps with the various components of EF that have been shown to be dissociable (Diamond, 2006) and are associated with different growth rates and developmental trajectories, namely (1) updating and monitoring of information in working memory, (2) inhibition of prepotent responses, and (3) cognitive flexibility or mental set shifting. To further illustrate that different authors have given different treatment of which components make up Executive Functions, the work of Pennington and colleagues identifies the following as an appropriate list: goal setting and management, planning, organized retrieval, speeded processing, hypothesis testing, and inhibition (Pennington & Ozonoff, 1996; Roberts & Pennington, 1996; Welsh et al., 1991).
Whereas most of the research on executive functioning skills has been conducted with adults, some developmental work suggests that prefrontal areas are at least partly functional earlier in childhood and children as young as 6 can show flexibility in strategic and planful behavior (Pennington & Ozonoff, 1996; Welsh et al., 1991). According to Diamond (2006), children show marked improvements in inhibition and cognitive flexibility between the ages of 3 and 5 years. These emerging cognitive advantages are evident on a variety of cognitive tasks such as the Dimensional Card Sort Task (in which children are asked to switch between two different card sorting strategies), the day-night Stroop like task (which requires inhibition of what various stimuli actually represent, as the child is required to say “day” to a picture of a moon and “night” to a picture depicting a sun) and a tapping task (in which the child is required to inhibit mimicking an experimenter’s action, and instead tap once when the experimenter taps twice and similarly tap twice when the experimenter taps once). On all of these tasks, children show improvements in percentage of correct responses over the preschool period.

In terms of the possible involvement of executive control in language learning, there is some conceptual and empirical work by Linda Smith (Smith, Colunga, & Yoshida, 2010) that highlights the role of attention in the very early stages of language learning. According to Smith’s attentional learning account (2000), attentional control is an important mechanism that facilitates early noun learning in infants and toddlers. This has been empirically supported by data showing that young children are able to attend to relevant perceptual features such as shape to categorize novel nouns (Yoshida & Smith, 2003). More specifically, when children at the age of 3 years are asked to choose among a set of novel objects that vary in terms of perceptual features (such as shape, color, material) and select the one that corresponds to a familiar noun, they are able to attend to the relevant perceptual feature and use this information to guide them in
their selection (for example, they will choose a round object when asked to point to the “egg”). On the other hand, when presented with a novel noun paired with an object, and then asked to select from a set of novel objects which one corresponds to the novel noun, they will revert to a shape-bias which is the perceptual feature most generally relevant across known object names. This work delineates the role of attentional mechanisms in early stages of vocabulary learning. Overall, Smith and colleagues also argue that attentional advances support vocabulary advances, and vice versa. However, a detailed empirical investigation of how a fuller set of attentional and executive control functions are implicated in vocabulary acquisition vs. acquisition of various syntactic structures and narrative skills in young children has yet to be conducted.

There is some empirical data on how various EF components relate to language outcomes in young children, but no single study has included a battery of measures assessing multiple executive components and how they may in combination account for variation in language skill levels. Additionally, no prior study has examined how these components relate differentially to vocabulary versus syntax or narrative performance in children. The following review focuses on the handful of studies that examine various EF components, including inhibitory control, retrieval and updating processes, and planning abilities in relation to language outcomes in children between the ages of 4 and 12.

Inhibitory control and language.

Very few studies have examined the relationship between inhibitory control abilities, or the ability to suppress a prepotent response, and language outcomes in preschool-aged children. In the rare cases in which such investigations have been conducted, researchers have varied in the type of task they have chosen for assessing inhibitory control abilities. Joseph, McGrath &
Tager-Flusberg (2005) for example found that inhibitory control as assessed by a knock-tap task positively correlated with language (vocabulary) abilities ($r = .35$) in typically developing children between the ages of 5 and 11 years (mean age= 8 years) after controlling for nonverbal intelligence abilities. The knock-tap task is a standardized measure that is very similar to the tapping task described earlier and requires the child to refrain from mimicking the examiner, as they are instructed to knock their knuckles on the table when the examiner taps with a flat palm and vice versa. This measure is also similar to the day-night task in that both require participants to hold an arbitrary response rule in working memory and to inhibit a prepotent response (i.e. to name the picture shown, to copy the hand movement of the examiner). However, it should be noted that even though the day-night task was also included in the test battery for executive control skills, scores on this measure did not significantly correlate with language in the typically developing group. Additionally, mixed results were found in a disordered group across these two tasks as well, as autistic children showed deficits in the knock-tap task compared to their typically developing peers but not on the day-night task. Finally, only receptive and expressive vocabulary was tested in this study, and so it remains unclear whether a similar relationship between inhibitory control and syntax would also have been observed.

In a separate study by Wolfe & Bell (2009), a strong association was found between inhibitory control, as assessed by both a day-night task and a yes-no task, and vocabulary in 4.5 year olds. Children with superior inhibitory control (those scoring above the median performance on a composite of the two tasks) had higher vocabulary scores. The yes-no task had a similar format to the other inhibitory control tasks that require children to inhibit a prepotent response of mimicking the examiner (in this case, the child was instructed to say “yes” when the examiner shook their head and vice versa). Thus, in a younger sample of children, inhibitory control tasks
that required inhibition of high frequency verbal labels (inhibiting the correct labels for “night” and “day” as well as for head motions corresponding to “yes” and “no”) was found to be related to a receptive vocabulary test. Again, given that syntax was not measured in this study, it remains unclear whether a relationship would hold between these inhibitory control skills and grammatical understanding or production.

One study that has examined the relationship between inhibitory control skills and grammatical abilities in preschoolers was conducted by Spaulding (2008). In this case, inhibitory control was assessed by accuracy on a go-no go task, in which children were required to inhibit a trained response (pressing the left button on a button box when presented with a picture of a dinosaur and the right button when presented with a picture of a butterfly) on “stop” trials but to make the appropriate response on “go” trials. Results indicated that accuracy on this measure was significantly correlated with standardized scores on both receptive ($r = .26$) and expressive ($r = .56$) syntax measures assessing sentence comprehension and production. Thus, there is at least some evidence that inhibitory control abilities may be related to syntax comprehension and production in children between the ages of 4 and 6 years. At the same time, it is important to recognize that this relationship in part may reflect the value of higher syntax levels (e.g. comprehending “Press the left one if you see a dinosaur”) in regulating behavior during the go-no-go task.

Conceptually, it may be argued that more complex syntactic structures such as passives and relative, and embedded, clauses that require activation and resolution of competing alternative structures may especially recruit and draw on inhibitory control skills (Mazuka, Jincho & Oishi, 2009). There is some evidence from a developmental study (Trueswell, Sekerine, Hill & Logrip, 1999) utilizing a visual world paradigm that 5 year old children, in
contrast to 8 year olds and adults, when presented with instructions such as “Put the frog on the
napkin in the box” are unable to revise their initial commitment to consider the modifier (“on the
napkin”) as the end destination for the object, and this is evident both in terms of their eye
movements (which don’t show the same pattern as the older children) as well as in terms of their
actions (as they proceed on the majority of trials to move the object to the napkin and then to the
final destination). This difficulty experienced by younger children in revising their initial
interpretation of such garden-path sentences has been attributed to immature cognitive control
abilities (Novick, Trueswell, & Thompson-Schill, 2010), and developmental changes in
cognitive control abilities are considered to be the mechanism driving performance on
comprehension of these complex relative clause structures. Further support for this notion that
comprehension of these more complex syntactic structures that have dual or competing
interpretations is supported by cognitive control resources comes from neuroimaging evidence
that the left inferior frontal gyrus (a brain region that has been linked to cognitive control) shows
increased activation for the processing of complex constructions like passives compared to
processing of the active form in adults (Ben-Shachar, Hendler, Kahn, Ben-Bashat, &
Grodzinsky, 2003). This finding has been interpreted as reflecting the need to bias interpretations
commitments away from the active or canonical form, to the less frequent passive form (Novick
et al., 2010). It remains an empirical question, however, as to whether individual differences in
young children’s abilities to comprehend and produce complex syntactic structures such as
passives and relative clauses can be accounted for by their inhibitory/cognitive control abilities.

In summary, the literature examining the relation between early developing inhibitory
control abilities and language skills is very limited, and the few studies that have conducted such
investigations have utilized different sets of measures to index inhibitory control and have
looked at only certain aspects of language (either vocabulary or syntax abilities, but not both). Wolfe and Bell (2009) found that performance on a day-night task was related to vocabulary in 4.5 year olds, but these two measures were not significantly associated in another study using an older sample of 5-11 year olds (Joseph et al., 2005), which found that only performance on a non-verbal knock-tap task was significantly related to vocabulary. Only one study has examined inhibitory control abilities in relation to syntactic abilities in preschoolers (Spaulding, 2008), and this study found using a go no-go task that inhibitory control was related to receptive and expressive syntax in 4-6 year olds. The current study will examine whether performance on the day-night task will show differential associations with syntax abilities relative to vocabulary skills and narrative skills in young children between 3½ and 6 years.

**Children’s Language in Relation to Multiple Executive Functions**

One important broad component of executive function that has been conceptually and empirically linked to language abilities has been variously referred to as “goal selection and management” (Pennington & Ozonoff, 1996), “attentional capacity” (Just & Carpenter, 1992) or “central executive resource control” (Baddeley, 1999). Whereas the tasks that have been used to index this capacity have varied in form, the function of this cognitive resource is pretty clearly related to the allocation in complex cognitive processing of attentional resources and monitoring resources to various subsystems and various goals/subgoals/plans. This function is handled by the “central executive” in Baddeley’s (2000, 2003) model of working memory which is responsible for allocating attentional resources to the phonological short term storage system for keeping information (such as words sequences) active in working memory, for activating relevant language representations for processing of linguistic stimuli (search and retrieval functions), for updating and manipulating information held in the short term storage buffer, and
for integrating prior representations with new incoming representations to form coherent sentence level representations—in the case of sentence-level processing (Montgomery et al., 2009). Pennington and Ozonoff (1996), in their review of tasks that assess EF as a molar construct, also describe these tasks as consisting of many dynamically interacting component process that are theoretically central to prefrontal cortex functioning, including set shifting and set maintenance, inhibition, integration across space and time, and planning. All of the studies reviewed below assess these EF skills in relation to language outcomes in children between the ages of 4 and 12 years (see also Roberts & Pennington, 1996; Miyake & Shah, 1999).

A study by de Abreu et al. (2011) found that cognitive control as assessed by a complex span index (a composite score of counting recall and backward digit span performance) manifested unique and robust links with syntax and early reading ability in 6 year olds. A highly relevant finding for the purposes of this study was that a dissociation was found between short term working memory and complex memory span and how each related to language outcomes; phonological working memory being related to vocabulary outcomes and not to syntax performance, whereas complex span was related to syntax but not vocabulary in these children.

A couple of studies have examined mental attentional capacity or “M capacity”, a construct developed by Pascual-Leone (1987) that refers to the number of mental schemas an individual can actively hold in mind at any given time, in relation to language abilities in school aged children. Morra & Camba (2009) for example found that M capacity (assessed by a figural intersections test in which children had to indicate the points of intersection between varying numbers of overlapping figures, a counting span task and a backward digit span task) was related to artificial vocabulary learning in 8-10 year olds. A separate study by Im-Bolter & Pascual-Leone (2006) found that M capacity (assessed here by a figural intersection test and direction
following task) was related to language outcomes (a composite score derived from standardized scores on a receptive phonology test and receptive and expressive vocabulary and syntax measures) in 7-12 year olds, and also that this relationship was mediated by updating skills (as assessed by proportion correct target identifications in the 1-back condition of an N-back task). Interestingly, inhibitory skills (as assessed by an anti-saccade task) were found to be strongly associated with mental attention capacity, but not with language abilities. The authors interpret these findings as possibly indicating that inhibitory control may contribute indirectly to language via an association with mental attention capacity. Similar studies for the age range 3 ½ to 6 years are lacking in the literature.

A related construct to M capacity that involves flexible allocation of resources for complex cognitive processing and dividing resources among two or more concurrent processes (such as linguistic processing and storage) has been referred to as attentional resource capacity (Baddeley, 1998, 2000). In adults, this capacity is typically indexed by complex operation span tasks in which individuals are required to perform some processing on either sentences or math operations while concurrently holding lexical items in short term memory (e.g. Turner & Engle, 1989; Engle, 2002). Developmentally appropriate correlates of this task have been used with younger children. Montgomery & Evans (2009) found that attentional/ goal-management resource capacity, as assessed by a competing language processing task (in which children made plausibility judgments about short sentences and then recalled the sentence final words) was moderately related ($r = .41$) to sentence comprehension (specifically to syntactically complex sentences including reversible “by” passives and pronominal sentences involving pronouns and reflexives) in 4.5 to 8 year olds (mean age= 6.25 years), even after controlling for age effects. Interestingly, this complex attentional/ goal management ability was not related to
comprehension of simple active sentences; nor was this effect found in group of older typically developing children or a group of age-matched language impaired children (mean age= 9 years, range= 8-11 years). This study stands alone as being one that examined multiple cognitive skills including both simple phonological working memory and more complex attentional/ goal management resources in relation to sentence comprehension in young children. The finding that attentional resource capacity, but not phonological short term memory, was related to sentence comprehension empirically validates the theoretical assumption that central executive resources would be especially implicated in sentence/ syntactic processing. Moreover, the finding that attentional resource capacity was related specifically to the processing of complex sentences, and not simple sentences, is consistent with the idea that challenging syntactic structures would differentially recruit these more complex processing resources that involve multiple subcomponents of the working memory system. These results were replicated in a study with slightly older children (mean age= 8 years, range= 6-12 years), as a listening span task was found to account for a unique proportion of variance (31%) in children’s complex, but not simple, sentence comprehension (Montgomery et al., 2008). Again, short term storage was not found to account for unique variance in sentence comprehension abilities.

A task that has been used widely to assess planning/ goal management abilities in disordered versus typically developing populations is the Tower of Hanoi task. This task evaluates a child’s ability to plan an organized sequence of moves such that they result in a final disk configuration that replicates the experimenter’s disk configuration. Fewer moves are associated with higher scores on this task, and thus successful performance on this task requires generating a strategy or plan, holding this plan in working memory, and updating and monitoring this plan after each move in order to achieve the end goal. These planning and goal management
skills are expected theoretically to particularly relate to learning of complex levels of syntax and narrative based on conceptual models of how information processing resources contribute to language acquisition (Just & Carpenter, 1992; Nelson et al., 2004; Case & Okamoto, 1996). Only a single study to our knowledge has examined how complex planning abilities using the Tower of Hanoi task relate to language abilities in young children. Joseph, McGrath and Tager-Flusberg (2005) found that planning abilities correlated significantly with vocabulary skills \((r = .39)\) in typically developing 5-11 year olds, even after controlling for the effects of nonverbal reasoning. Syntax and more complex language abilities were not assessed in this study though, so it remains an empirical question as to whether planning abilities would relate to syntax abilities in young children. It should also be noted that the age range across which this relationship was examined is quite broad. It remains unclear whether planning abilities would relate similarly to vocabulary in children between the ages of 3 ½ and 6 years and whether we would see differential links with complex aspects of syntax and narrative abilities.

Search and retrieval of information from long term memory has also been examined in the form of verbal fluency tasks. These tasks require individuals to generate as many exemplars as possible belonging to a particular category (for example, “fruits”) in a sixty second interval, and performance on this task taps the individual’s ability to maintain the specified category as a goal and to retrieve and organize lexical exemplars in an open-ended production context with constant monitoring of each step and with appropriate inhibition of prior exemplars. Adams, Bourke & Willis (1999) found that verbal fluency performance exhibited unique and independent associations (explaining an additional 13% of total variance) with language comprehension in typically developing 4 to 5 year olds. A comprehension scale of the Reynell developmental language scales was used to assess language ability, measuring a range of linguistic components
and constructions including: single words, agents and actions, subject-verb-object constructions, adjectives, locative relations, passives and post-modifying clauses. An important dissociation between phonological working memory skills and executive goal resource management skills in how they relate to language outcomes was found in this study as well. Variance in vocabulary knowledge was best explained by phonological memory skills, whereas individual differences in spoken language comprehension exhibited unique and independent associations with verbal fluency performance as an indicator of attention/ retrieval/ goal-management executive skills.

Only a single study has investigated whether any kind of executive control abilities are related to narrative performance in young children. Montgomery, Polunenko and Marinellie (2009) found that central executive skill as assessed by a concurrent verbal processing and storage task (listening span task) correlated significantly ($r = .54$) with narrative comprehension (assessed by a series of prompted comprehension questions regarding stories from a standardized narrative measure) in 6-11 year olds. After accounting for age, the listening span task accounted for a significant 7.9% of unique variance in narrative comprehension ability. These results are not surprising given the theoretical predictions that narrative comprehension would draw substantially on executive control resources due to high demands on working memory (keeping story structure in mind along with processing of each successive sentence), on the rapid processing and integration of information (including information regarding the causal structure of the story, resolution of problems in the story), and on goal management (analyzing new sentences while keeping track of the unfolding story structure) in a story-listening context. It remains unclear as to whether similar executive function contributions to narrative skill would hold at younger ages.
To summarize, there are very few results available for how Executive Function processes of planning, goal setting and shifting, attentional selectivity and allocation, monitoring and integration relate to language abilities in 3 ½-to 6 year old children. The overall picture that emerges from the few available results suggests that syntactic abilities may be particularly susceptible to individual differences in these cognitive processes. Furthermore, there seems to be a dissociation between complex versus simple sentence comprehension abilities in how they relate to complex span, with a competing language task (requiring goal and resource management) being related to the comprehension of complex sentences in 4.5- 8 year olds but not for 8-11 year olds (Montgomery & Evans, 2009), and a listening span task being related to complex (but not simple) sentence comprehension in 6-12 year olds (Montgomery et al., 2008).

There is also limited evidence for the relation between planning abilities and language abilities in young children. A single study found a relation between Tower of Hanoi planning abilities and vocabulary abilities across a pretty broad age range (5-11 years). It therefore remains unclear whether planning skills would be related to vocabulary abilities in younger children and whether these planning skills would support syntax and narrative performance as well. Finally, there is some empirical evidence that search and retrieval processes as assessed by a verbal fluency task (requiring goal maintenance, focused retrieval, monitoring, and inhibitory control) are related to language outcomes in 4-5 year olds (Adams, Bourke & Willis, 1999). This study used a global measure of language, however, that included single word items as well as complex sentences and so it remains an empirical question as to whether verbal fluency performance shows differential links to vocabulary, syntax, and narrative skills in young children. In regards to narrative outcomes, only one study has examined the relation between central executive abilities and narrative, and there is some indication that this resource may be place constraints on narrative
comprehension abilities in school-aged children. The current study will address the empirical question of what the differential links between multiple EF tasks and language skills look like in the 3 ½ -6 year age range across three different domains including vocabulary, syntax and narrative abilities.

Summary of Findings on Multiple Information Processing Skills and Language

Overall, the information processing component that has been examined most extensively in relation to early developing language abilities is short-term phonological working memory. And multiple sources of evidence converge to indicate that this cognitive resource often shows links with vocabulary skills in the 3 ½ to 6 year early childhood period. In contrast, phonological working memory has shown to be related only to certain early syntax abilities and has only been examined in very few studies. The link between phonological working memory and narrative skills is even less clear, and more research needs to be done to examine whether this information processing component is important at the early stages of narrative development.

The research on individual differences in distinct components of executive function and how these relate to, and support, language abilities in young children is also severely lacking. The couple of studies that have utilized a day-night or tapping task (developmentally appropriate tasks for assessing inhibitory control abilities in preschoolers) and examined these in relation to language have reported different results in regards to vocabulary outcomes; with day-night task performance being related to vocabulary in 4.5 year olds, but only a tapping task being associated with vocabulary in 5-11 year olds. Another component of EF, namely attentional/goal management, when assessed by dual processing language tasks has been shown to be specifically associated with complex syntax abilities in young children across a couple of different studies,
and with narrative ability in a single study. However, the age range employed in these studies was quite broad, and it remains an empirical question as to whether central executive resources exhibit strong and differential links to complex syntax comprehension abilities at ages 3, 4, 5 and 6 years. There is some evidence that processing speed is a separable construct from working memory in school-aged children (Leonard et al., 2007), and that it is related to global language outcomes.

Overall, considering the prior literature, a much more detailed examination of how phonological working memory and a differentiated set of Executive Function abilities contribute to young children’s narrative, syntax, and vocabulary acquisition is warranted.

**Current Study**

**Research Questions and Hypotheses**

The current study aims to address the following empirical questions:

**Question 1.** How do multiple information processing skills including phonological short term working memory (2 measures) and differentiated Executive Functions (EF) relate to emerging narrative skills in typically developing children between the ages of 3 ½ and 6 years? Predictors of children's levels of narrative skills include simple EF measures of processing speed, inhibitory control, planning, and updating, and complex EF measures which tap a richer set of functions including goal setting and management, goal-directed search and retrieval, monitoring, shifting, inhibition, coordination, and attentional flexibility. Will a different set of cognitive skills better account for variance in children's production vs. comprehension of narrative skills for this age range?
**Question 2.** How do multiple information processing skills including phonological short-term working memory (2 measures) and differentiated Executive Functions (EF) relate to emerging *syntax* skills in typically developing children between the ages of 3 ½ and 6 years? Predictors of children's levels of *syntax* skills include simple EF measures of processing speed, inhibitory control, planning, and updating, and complex EF measures which tap a richer set of functions including goal setting and management, goal-directed search and retrieval, monitoring, shifting, inhibition, coordination, and attentional flexibility. Will a different set of cognitive skills better account for variance in production vs. comprehension of *syntax* skills for this age range?

**Question 3.** Will the pattern of predictive relationships between the cognitive variables and language outcomes be similar for simple syntactic structures compared to more complex syntactic structures?

**Question 4.** How do multiple information processing skills including phonological short-term working memory (2 measures) and differentiated Executive Functions (EF) relate to emerging *vocabulary* skills in typically developing children between the ages of 3 ½ and 6 years? Predictors of children's levels of *vocabulary* skills include simple EF measures of processing speed, inhibitory control, planning, and updating, and complex EF measures which tap a richer set of functions including goal setting and management, goal-directed search and retrieval, monitoring, shifting, inhibition, coordination, and attentional flexibility. Will a different set of cognitive skills better account for variance in production vs. comprehension of *vocabulary* skills for this age range?
It is hypothesized that only greater phonological short term working memory will be related to superior vocabulary skills, but that superior emerging syntax and narrative skills will be related to a more complex profile of cognitive skills that includes both simple EF and complex EF skills.

It is further hypothesized that higher levels of unique variance will be attributed to complex EF skills for complex syntax as compared with simpler syntax.
Method

Participants

Participants included a total of 84 typically developing children, ranging in age from 3 years 6 months to 5 years 11 months ($M = 4.5$ years, $SD = 0.62$ years). The sample consisted of 50 boys and 34 girls. In terms of racial/ethnic breakdown, the majority of the sample was Caucasian (86%) with the remainder consisting of Asians and African Americans. In terms of language background, the majority of children were monolingual English speakers with a small percentage (11%) being bilingual. All children were typically developing and free of any language or other developmental delays. Children were recruited primarily through the FIRSt (Families Interested in Research Studies) database maintained at the Child Study Center (CSC) at Penn State University. Family contact information was obtained through this database and recruitment letters were mailed to parents whose children met the age criteria for the study. Parents were then contacted via phone calls that outlined eligibility criteria, study procedures and compensation details. Another recruitment strategy that was employed was distributing study flyers to local daycares in State College. All of the families that participated in this study were thus residents of Central Pennsylvania and lived within a 60 mile radius of State College.

Measures

Language Measures

Vocabulary was assessed using two tasks. Receptive vocabulary was measured via the verbal knowledge subtest of the Kaufman Brief Intelligence Test, 2nd edition (KBIT2; Kaufman & Kaufman, 2004). During this task, children were shown an array of six pictures and were asked to point to the picture that matched a particular word (e.g. “Point to gift”). The test was
discontinued after four consecutive errors. Raw scores on this subtest ranged from 1 to 60 points. Additionally, in order to obtain parallel measures for receptive and expressive vocabulary, the Peabody Picture Vocabulary Test materials were used such that items alternated between receptive and productive items. Children were asked to either point to a particular item from a set of four pictures or name a picture/identify the action depicted in the target picture. Forty items ranging in complexity were used in this manner and items were scored on a 0 to 2 scale, with partial credit being granted to expressive items that were close to the correct response (e.g. “tying” instead of “wrapping”). Thus, receptive and productive vocabulary scores each ranged from 0 to 40 points. An average z-score was calculated for the verbal knowledge subtest and the receptive vocabulary adapted PPVT measure to reflect each child’s receptive vocabulary skills.

Syntax was assessed using three measures. The first task used to assess expressive syntax ability was the syntax construction subtest of the Comprehensive Assessment of Children’s Language (CASL; Carrow-Woolfolk, 1999). This task requires children to complete sentences by producing a word or phrase that is semantically and grammatically appropriate to the context. Each item targets specific syntactic forms and requires the child to keep syntactic rules in mind when producing a response. Raw and standardized scores were calculated for this measure.

The second measure used to assess syntax was an adapted version of a sentence imitation task used by Willis and Gathercole (2001), which these researchers adapted from the Test for Reception of Grammar (TROG; Bishop, 1983). Children were asked to repeat sentences that ranged in terms of syntactic complexity. The syntactic structures that were assessed included relatively simple constructions such as prepositions (e.g. “The doll is on the box”) and short passives (“The books are read by the mom”) and more complex structures that combined multiple elements such as a coordinated conjunction plus relative clause structure (e.g. “If the
boy with the hat runs, then he will get on the bus.”) Eighteen items were included on this measure. Each item was scored on a 0 to 5 scale, with perfect imitations being awarded a perfect score, imitations that were slightly different but preserved the syntax and meaning of the sentence were awarded 4 points, whereas imitations that preserved the syntactic structure of the sentence but were accompanied by a slight change in the meaning of the sentence were assigned a score of 3 points. Consistent with scoring rules for the recalling sentences sub-test of the Clinical Evaluation of Language Fundamentals – Preschool ( CELF; Wiig, Secord & Semel, 1992), any additions, deletions or substitutions on the part of the child were counted as errors. Thus, 1 to 2 errors resulted in a score of 2 points, 3 errors resulted in a score of 1 point, and responses with more than 3 errors resulted in a score of 0.

A parallel comprehension measure was also created that tested children’s ability to comprehend sentences ranging in syntactic complexity. The same 18 syntactic structures from the sentence imitation task were used to construct materials for this measure. On any given trial, children were shown three pictures and were asked to choose the picture that best matched the meaning of the sentence that presented to them orally. Each set of pictures contained a close competitor item and a foil in addition to the target picture. Thus, a scoring scheme of 0-2 points was used, where partial credit was awarded to choosing the competitor item rather than the more egregious error of choosing the foil. In order to examine predictors of simpler vs. more complex syntactic structures, items were separated for both the sentence repetition and comprehension measures into 9 simpler structures and 9 more complex structures.

Narrative ability was assessed using a standardized story-retelling task, the adapted version (Glasgow & Cowley, 1994) of the Bus Story (Renfrew, 1977). The story has a total of 12 pictures with a corresponding 168-word script that was read to the child by the experimenter.
The child was then asked to re-tell the story with the aid of the pictures. The children’s retellings were recorded using a digital recorder. These narratives were scored for overall content based on instructions provided by Glasgow and Cowley (1994). This test has adequate test-retest ($r=.70$) reliability for scoring the information contained within the child’s narrative. Raw scores on this narrative production measure ranged from 0 to 53 points. To assess narrative comprehension, children were asked a series of 8 questions pertaining to the story. Scores on this comprehension test were calculated on a 0 to 1 scale, with partial credit being awarded to responses that were relevant but not entirely accurate. The maximum possible score on the narrative comprehension task was therefore 8 points.

**Cognitive Information-Processing Predictors**

**Verbal Short-Term Working Memory.** Verbal short term working memory was measured using two tasks: a nonword repetition task and forward digit span task. The Children’s Test of Nonword Repetition (CN Rep; Gathercole & Baddeley, 1996) requires children to repeat nonwords that the experimenter says out loud (such as "balop"). The test consists of phonologically acceptable nonwords, containing one, two or three syllables. Total number of correct repetitions was scored for each child, with a maximum possible score of 20. This task draws on the ability to store one item of information in very short-term working memory and then repeat the item, but does not require manipulation of that information; thus, it can be considered a measure of basic phonological short-term working memory.

The second task that was used to assess verbal working memory was a forward digit span task. This task required participants to repeat a spoken series of digits (for example, "1 2 3 4 5") to the experimenter. The task consisted of six trials with sequence length commencing at two digits and ending at five digits. Scores on individual trials were weighted by digit length (2x2,
3x3, 4x4 and 5x5). Additionally, partial credit was awarded to repetitions on the 4 and 5-digit trials in which children successfully produced part of the sequence (i.e. at least 3 correct digits in a row) and managed to avoid including digits that were not present in the original sequence. The maximum possible score on this measure was 79 points. Similar to the nonword repetition task, this task simply reflects an individual’s very short term working memory capacity or the ability to hold a sequence of digits in a phonological storage space and then retrieve and repeat the digits in the correct order.

**Central Executive/ Goal Resource Management.** Seven tasks were used to assess various aspects of this construct including the Rapid Naming, Day-Night, Backward Digit Span, Sentence Completion and Recall, Tower of Hanoi, Dimensional Change Card Sorting (DCCS) and Verbal Fluency tasks.

The Backward Digit span, Sentence Completion and Recall task and Day-night Stroop task have all been categorized as complex working memory tasks in the cognitive developmental literature (see Gathercole, 1999). In contrast to phonological short term working memory tasks, these tasks recruit the “Central Executive” (Baddeley, 2000) which is considered to be a limited capacity system responsible for multiple functions some of which include storage and retrieval processes, the control of attention, and planning. Additionally, these tasks differentially recruit the prefrontal cortex which is typically activated in tasks that require higher order executive control processes (Pennington & Ozonoff, 1996).

The current thesis expands upon the set of tasks assessing central executive/ goal resource management to also include the Rapid Naming, Tower, DCCS and Verbal Fluency tasks. The complexity of these executive function (EF) tasks in terms of the cognitive demands imposed by each task and the number of processing components or functions required for
successful performance on each task are paid special consideration. This yields two groups: simple EF and complex EF. Simple EF included the following tasks each with 3 to 4 component functions: Rapid Naming, Backward Digit Span, Sentence Completion Recall, Day-night and Tower. Complex EF included the following tasks each with 6 to 7 component functions: Card Sorting and Verbal Fluency.

Processing speed was measured using the Rapid Automatized Naming Test (Wolf & Denckla, 2005), which required the participant to name colors and familiar objects as rapidly as possible. A stop watch was used to record the total amount of time it took the children to name the colors and objects. An average z-score was computed for color naming and object naming and this composite score was used in subsequent analyses. This task reflects intentionally speeded processing in two ways: speed of retrieving names for colors and objects, and speed of producing the names. The task also engages some simple inhibitory control skills as the same set of six colors or objects appear multiple times in this task, and so there is a need to inhibit five other recently multiply-primed vocabulary items when for example *pencil* occurs as the picture to name as item 20 or so on. Finally, executive function goal setting was required in that the task required not only the simpler goal of retrieving appropriate lexical items but also the goal of doing so *rapidly.*

In the Day-night task (as employed by Gerstadt, Hong & Diamond, 1994), children were required to pay attention to a set of rules and to inhibit a dominant response (e.g. saying “day” when being shown a drawing of a sun) in order to perform a non-dominant response (e.g. saying “night” when being shown a picture depicting day). All children were required to reach a baseline criterion of naming each of the two types of cards correctly before being administered the 20 actual trials. In terms of the processing steps required for successful performance on this
task, participants were required to engage in simple goal setting (internalizing the set of goals that they were to say “day” when shown a picture of night and vice versa), inhibition of the prepotent response, and retrieval/production of the appropriate labels for each card (for e.g., saying day and not sun or saying night and not moon).

The Backward Digit Span task required participants to repeat a spoken series of digits in the reverse order, for example, saying “4 3 2” in response to “2 3 4” said by the experimenter. Sequence length commenced at two digits and ended at four digits. Six trials were administered in total and trials were weighted by digit-length as described for the forward digit span task. Partial credit was awarded for responses that indicated the beginnings of a successful reversal and at least started with the last digit of the original sequence. The maximum possible score on this task was 76 points. This task, unlike the forward digit span task, requires an operation to be performed on the input (i.e. reversal and re-ordering of the numbers) in addition to holding the information in working memory and therefore assesses central executive skills rather than simple phonological working memory capacity. More specifically, this task requires the coordination of all these components processes: goal setting (maintaining original order in memory, then reversing digits while recalling); inhibition of the prepotent response of saying the digits in the original order; monitoring of the recall process so that only the digits on this trial are produced; and producing the manipulated digits in the reverse order of presentation.

A modified Tower of Hanoi task was used to assess planning abilities and related EF abilities in young children. In this task, children were required to move three different colored discs on three vertical pegs to achieve a goal state which was depicted in an identical apparatus that the experimenter manipulated. In contrast to the standard Tower of Hanoi rules, the number of moves was not restricted. However, the participants were instructed that they could only move
one disc at a time. Eight trials were administered which increased in difficulty in terms of number of moves required to reach the end state (ranging from 1 move to 6 moves). Scores on each trial were weighted by the least number of moves required for that trial (a 3-move trial had a maximum possible score of 3 points etc.) and a point was deducted for each additional move that the child used beyond the most efficient solution for that trial. The maximum possible score on this task was 24 points. This task has been widely used as a measure of goal management abilities in adults and has also shown good discrimination of individual differences in planning abilities in children when it has been employed (see Pennington & Ozonoff, 1996). In terms of the various processing steps involved, this task requires setting the goal of matching the experimenter’s disc display, planning (visualizing how discs need to be moved to attain goal configuration), goal monitoring (checking what next move should be made in order to achieve the final configuration after each subsequent move is made), making the appropriate disc moves, and inhibitory control (resisting the urge to move more than one disc at a time or move a disc to the final peg without considering necessary intermediate moves).

EF functions at a relatively simple level were also measured by a sentence completion and recall task (as employed by Adams & Willis, 1999). In this task, children listened to a series of short sentences with a missing word at the end, for e.g. “I can see with my ____” They were asked to complete each sentence and then recall the final words that they produced for each sentence in a particular set. A total of four trials were administered with two 2-sentence sets and two 3-sentence sets. Scores were weighted by set size such that if a child correctly recalled 2 of the 3 words from a 3-sentence set, then they received a score of 6 (2x3). The maximum possible score on this task was 26 points. In terms of processing steps, this task required goal setting (complete sentence and hold final word in working memory for later recall), updating (adding
each new word to list of words to be recalled), attentional selectivity to retrieval of the word list, and inhibitory control (only recalling final words from the current trial; not other words comprising the sentences or final words from sentences in previous trials).

The Dimensional Change Card Sorting (DCCS) task (Zelazo, 2006) assesses a complex set of EF skills. Children were given practice sorting cards into boxes based on two different sorting rules (i.e. sorting cards by shape or by color) and were then required to reach a criterion of successfully sorting six consecutive cards by color before the sorting criterion was switched and the 12 post-switch trials were administered. Successful performance on this task required the coordination of multiple processes: goal setting (goal to sort cards based on whichever rule is active, color or shape), activation (activating the appropriate dimension), selective attention (when asked to sort by shape, attend only to the relevant dimension of shape), placing the cards in the boxes, inhibitory control (suppress the prepotent response of sorting by the pre-switch rule and suppressing the irrelevant dimension), shifting the goal/rule at the "switch point", monitoring, and coordination (ensure for example that red rabbits go in the blue rabbit box and blue boats go in the red boat box).

A verbal fluency task was also used to assess complex executive function skills, including search and retrieval from long term memory/selection and manipulation of information stored in long term memory. Children were presented with three categories, “things to eat”, “animals” and “things to wear,” and provided 60 seconds to generate as many exemplars belonging to each category as possible. The total number of appropriate responses was tallied for the total score on this measure. This task has been used to assess executive function skills in both children and adults and requires the coordination of the following processes: activation (activating the appropriate semantic category), using the category as a goal in item generation
and setting speed as another goal, selectivity of attention and retrieval (retrieval of appropriate exemplars from a given category), production of the exemplar name, monitoring (monitoring of ongoing production to avoid repetition or errors), shifting to each new category as a goal, coordination, and two aspects of inhibitory control (inhibition of previously activated items or associations to those items, and inhibition of previously activated categories).

**Procedure**

All data collection took place in a research lab on Penn State’s campus. The study was completed across two sessions, each session lasting about 35-45 minutes. The two sessions were separated by no longer than one week. During session 1, the parent signed a consent form and completed a brief survey asking about the child’s language background and whether or not their child had received speech and/or language therapy. All of the tasks were administered orally and required children to respond verbally or manipulate objects or point as appropriate. A 5-10 minute break was provided to each child at the half-way point of each session. All children were presented with the same order of tasks and completed the following eight tasks during session 1: Tower, Verbal Knowledge, Sentence Repetition, Verbal Fluency, Bus Story, Rapid Naming, Forward Digit Span and Backward Digit Span. During session 2, children completed the following seven tasks: Sentence Completion and Recall, Day-night, Sentence Comprehension, Card Sorting, CASL, Nonword Repetition and PPVT. To maintain attention and engagement during the session, children were offered a chart stamping activity after successful completion of each task. Children tracked their progress through the session by choosing from an assortment of fun self-inking stamps and stamping their stamp chart, which they were allowed to take home as a souvenir.
Results

Factors Related to Narrative Skills in Young Children

The nine possible predictor variables (Nonword Repetition, Forward Digit Span, Rapid Naming Speed, Day-night, Card-sorting, Backward Digit Span, Tower, and Verbal Fluency) were entered as predictors in a backwards elimination multiple regression model, with narrative production as the outcome variable. The final stage of the model accounted for 39.9% of the variance in narrative production scores across all children, and included only four variables: Card sorting, Tower, Verbal Fluency, and Rapid Naming speed (see Table 1). Card Sorting was the most significant predictor of narrative production, $\beta = .266, p < .01$, followed by Tower, $\beta = .22, p < .05$, and Verbal Fluency, $\beta = .209, p < .05$. A trend was also observed for a relation between Rapid Naming Speed and narrative production, $\beta = -.18, p = .075$. It should be noted that the two tasks that recruited multiple cognitive processes, i.e. the Card Sorting task and Verbal Fluency task, were both included as significant predictors of narrative production.

Table 1. Results of multiple regression analysis with narrative production as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Speed- Simple EF</td>
<td>-.18</td>
<td>-1.81</td>
<td>.075</td>
</tr>
<tr>
<td>Tower of Hanoi Planning- Simple EF</td>
<td>.22</td>
<td>2.24</td>
<td>.028</td>
</tr>
<tr>
<td>Card Sorting &amp; Switching- Complex EF</td>
<td>.27</td>
<td>2.68</td>
<td>.009</td>
</tr>
<tr>
<td>Verbal Fluency- Complex EF</td>
<td>.21</td>
<td>2.00</td>
<td>.049</td>
</tr>
</tbody>
</table>

The same nine predictors were entered as predictors in a backwards elimination model with narrative comprehension as the outcome. In this case, the reduced model accounted for
46.1% of the variance in narrative comprehension scores across the entire sample. A somewhat overlapping set of predictors were included in the final model including Sentence Completion and Recall, Card Sorting, Verbal Fluency and Tower (see Table 2). Sentence Completion and Recall, $\beta = .297, p < .01$ and Card Sorting, $\beta = .27, p < .01$ were the significant predictors of narrative comprehension abilities, whereas Verbal Fluency, $\beta = .177, p = .079$ and Tower, $\beta = .162, p = .083$ approached significance. Thus, consistent with the results for narrative production, Card Sorting and Verbal Fluency were implicated in story comprehension and reasoning abilities as well.

**Table 2.** Results of multiple regression analysis with narrative comprehension as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower of Hanoi Planning- Simple EF</td>
<td>.16</td>
<td>1.75</td>
<td>.083</td>
</tr>
<tr>
<td>Sentence Completion Recall Span- Simple EF</td>
<td>.30</td>
<td>2.92</td>
<td>.005</td>
</tr>
<tr>
<td>Card Sorting &amp; Switching- Complex EF</td>
<td>.27</td>
<td>2.73</td>
<td>.008</td>
</tr>
<tr>
<td>Verbal Fluency- Complex EF</td>
<td>.18</td>
<td>1.78</td>
<td>.079</td>
</tr>
</tbody>
</table>

**Factors Related to Syntax Skills in Young Children**

All nine tasks (Nonword repetition, Forward Digit Span, Rapid Naming Speed, Day-night, Card-sorting, Backward Digit Span, Tower, and Verbal Fluency) were entered as predictors in a backwards elimination model with syntax production as the outcome variable. The reduced model accounted for 57.5% of the variance in syntax production scores across the
entire sample. Six of the nine predictors were included in the final model including Nonword Repetition, Card Sorting, Forward Digit Span, Backward Digit Span, Sentence Completion and Recall and Day-Night (see Table 3). The tasks assessing phonological short term memory were both significant predictors of sentence repetition, with Nonword Repetition emerging as a stronger predictor, $\beta = .302, p < .001$, than Forward Digit Span, $\beta = .21, p < .05$. Card Sorting was also a significant predictor of syntax production, $\beta = .233, p < .01$, with Backward Digit Span just approaching significance, $\beta = .177, p < .05$. And finally, Sentence Completion and Recall showed a trend toward significance, $\beta = .175, p = .06$, as did the Day-night task, $\beta = .145, p = .067$. These results implicate the multiple processes that support Card Sorting and phonological short term working memory in the ability to successfully imitate sentences that range in terms of syntactic complexity. More complex working memory abilities and some inhibitory control seem to also be related to sentence repetition abilities.

Table 3. Results of multiple regression analysis with syntax production as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonword Repetition-PhonWM</td>
<td>.30</td>
<td>3.68</td>
<td>.000</td>
</tr>
<tr>
<td>Forward Digit Span-PhonWM</td>
<td>.21</td>
<td>2.65</td>
<td>.010</td>
</tr>
<tr>
<td>Inhibition Day-Night-Simple EF</td>
<td>.15</td>
<td>1.86</td>
<td>.067</td>
</tr>
<tr>
<td>Backward Digit Span-Simple EF</td>
<td>.18</td>
<td>2.00</td>
<td>.049</td>
</tr>
<tr>
<td>Sentence Completion Recall Span-Simple EF</td>
<td>.18</td>
<td>1.90</td>
<td>.061</td>
</tr>
<tr>
<td>Card Sorting &amp; Switching-Complex EF</td>
<td>.23</td>
<td>2.71</td>
<td>.008</td>
</tr>
</tbody>
</table>
When the same nine variables were entered as predictors for syntax comprehension, the reduced model accounted for 38.3% of the variance in sentence comprehension and the included the following three variables: Tower, Sentence Completion and Recall and Card Sorting (see Table 4). All three were significant predictors of syntax comprehension, with Tower $\beta = .29$, $p < .01$, and Sentence Completion and Recall, $\beta = .27$, $p < .01$ being the most significant predictors followed by Card Sorting, $\beta = .253$, $p < .05$. Thus, in contrast to sentence production, successful comprehension of the same set of sentences does not draw upon phonological short term working memory in a similar manner. However, similar to production, comprehension taps into the multiple processes underlying Card Sorting performance and is supported by better goal management skills and greater working memory resources.

**Table 4.** Results of multiple regression analysis with syntax comprehension as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower of Hanoi Planning</td>
<td>.29</td>
<td>3.02</td>
<td>.003</td>
</tr>
<tr>
<td>Simple EF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sentence Completion</td>
<td>.27</td>
<td>2.72</td>
<td>.008</td>
</tr>
<tr>
<td>Recall Span- Simple EF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Card Sorting &amp; Switching</td>
<td>.25</td>
<td>2.42</td>
<td>.018</td>
</tr>
<tr>
<td>Complex EF</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Factors Related to Processing of Simple vs. Complex Syntactic Structures**

A backwards elimination multiple regression method was used to identify the best-fitting models for comprehension and production performance on simpler syntactic structures compared to relatively complex syntactic structures. For sentence production of only the simpler structures,
46% of the variance was accounted for by Nonword Repetition, Sentence Completion and Recall, Day-night and Forward Digit Span (see Table 5). All four variables were significant predictors of production of simple syntactic structures, with Nonword Repetition, $\beta = .396, p < .001$, and Sentence Completion and Recall, $\beta = .288, p < .01$ being the strongest predictors followed by Day-night $\beta = .201, p < .05$ and Forward Digit Span, $\beta = .177, p < .05$. Thus, verbal short term working memory and executive memory, as well as some inhibitory control appear to support the processing and imitation of simpler syntactic structures.

Table 5. Results of multiple regression analysis with syntactic production for simple structures as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>$t$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonword Repetition-PhonWM</td>
<td>.40</td>
<td>4.40</td>
<td>.000</td>
</tr>
<tr>
<td>Forward Digit Span-PhonWM</td>
<td>.18</td>
<td>2.05</td>
<td>.044</td>
</tr>
<tr>
<td>Inhibition Day-Night-Simple EF</td>
<td>.20</td>
<td>2.38</td>
<td>.020</td>
</tr>
<tr>
<td>Sentence Completion Recall Span- Simple EF</td>
<td>.29</td>
<td>3.38</td>
<td>.001</td>
</tr>
</tbody>
</table>

For production of more complex syntactic structures, backwards elimination yielded a reduced model containing six variables. This model accounted for 57.8% of variance in complex sentence production performance and included Backward Digit Span, $\beta = .246, p < .01$, Card Sorting, $\beta = .225, p < .01$, Forward Digit Span, $\beta = .198, p < .05$, Nonword Repetition, $\beta = .184, p < .05$, Tower $\beta = .179, p < .05$, and Verbal Fluency, $\beta = .160, p = .074$ (see Table 6). As expected, the more complex tasks such as Card Sorting and Verbal Fluency become relevant for processing
and imitation of complex syntactic structures in addition to executive memory and short term working memory.

**Table 6.** Results of multiple regression analysis with syntactic production of more complex structures as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonword Repetition-PhonWM</td>
<td>.18</td>
<td>2.22</td>
<td>.029</td>
</tr>
<tr>
<td>Forward Digit Span-PhonWM</td>
<td>.20</td>
<td>2.48</td>
<td>.015</td>
</tr>
<tr>
<td>Backward Digit Span-Simple EF</td>
<td>.25</td>
<td>2.84</td>
<td>.006</td>
</tr>
<tr>
<td>Tower of Hanoi Planning- Simple EF</td>
<td>.18</td>
<td>2.05</td>
<td>.044</td>
</tr>
<tr>
<td>Card Sorting &amp; Switching- Complex EF</td>
<td>.23</td>
<td>2.66</td>
<td>.009</td>
</tr>
<tr>
<td>Verbal Fluency-Complex EF</td>
<td>.16</td>
<td>1.81</td>
<td>.074</td>
</tr>
</tbody>
</table>

The best-fitting model for comprehension of simple syntactic structures accounted for only 13.8% of the variance and included a single variable—performance on the Tower task, \( \beta = .372, p = .001 \) (see Table 7).

**Table 7.** Results of multiple regression analysis with syntax comprehension on simple structures as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tower of Hanoi</td>
<td>.37</td>
<td>3.62</td>
<td>.001</td>
</tr>
</tbody>
</table>
In contrast, the best fitting reduced model obtained through backwards elimination for comprehension of the more complex syntactic structures accounted for 32.3% of the variance on this outcome and included Card Sorting, $\beta = .337, p < .01$, and Sentence Completion and Recall, $\beta = .328, p < .01$ (see Table 8). Once again, processing of more complex syntactic structures was shown to be related to Card Sorting abilities which are supported by multiple cognitive processes in contrast to the processing of simpler structures which seems to draw on simpler processes.

**Table 8.** Results of multiple regression analysis with syntax comprehension on complex structures as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentence Completion Recall Span</td>
<td>.33</td>
<td>3.20</td>
<td>.002</td>
</tr>
<tr>
<td>Card Sorting &amp; Switching-Complex EF</td>
<td>.34</td>
<td>3.28</td>
<td>.002</td>
</tr>
</tbody>
</table>

**Factors Related to Vocabulary Skills in Young Children**

Using the backwards elimination multiple regression method, only four predictor variables were found to be significantly related to productive vocabulary skills in children between 3.5 years and 6 years. These four variables included Sentence Completion and Recall, Backward Digit Span, Tower and Day-night, and accounted for 40.6% of the variance in productive vocabulary across the entire sample (see Table 9). Sentence Completion and Recall was the most significant predictor in the model, $\beta = .321, p < .01$, followed by Backward Digit Span, $\beta = .239, p < .05$, Tower, $\beta = .206, p < .05$, and Day-night, $\beta = .19, p < .05$. 
Table 9. Results of multiple regression analysis with vocabulary production as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibition Day-Night-</td>
<td>.19</td>
<td>2.12</td>
<td>.037</td>
</tr>
<tr>
<td>Simple EF</td>
<td></td>
<td></td>
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<tr>
<td>Backward Digit Span-</td>
<td>.24</td>
<td>2.38</td>
<td>.020</td>
</tr>
<tr>
<td>Simple EF</td>
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<td></td>
<td></td>
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<tr>
<td>Tower of Hanoi Planning</td>
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<td>2.23</td>
<td>.028</td>
</tr>
<tr>
<td>Simple EF</td>
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<td></td>
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<tr>
<td>Sentence Completion</td>
<td>.32</td>
<td>3.26</td>
<td>.002</td>
</tr>
<tr>
<td>Recall Span- Simple EF</td>
<td></td>
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</table>

The backwards elimination method yielded a reduced model with only three variables when receptive vocabulary was the outcome variable. This model accounted for 42.7% of the variance in receptive vocabulary across the entire sample and included Sentence Completion and Recall, Tower and Day-night (see Table 10). All three variables were significant predictors of receptive vocabulary with Sentence Completion and Recall emerging as the strongest predictor, $\beta = .468$, $p < .001$, followed by Tower, $\beta = .247$, $p < .01$ and Day-night, $\beta = .24$, $p < .01$.

Table 10. Results of multiple regression analysis with receptive vocabulary as the outcome variable.

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
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<tr>
<td>Sentence Completion</td>
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<td>5.35</td>
<td>.000</td>
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<td>Recall Span- Simple EF</td>
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</table>
Question 1. How do multiple information processing skills relate to emerging narrative skills in typically developing children between the ages of 3 ½ and 6 years? Will a different set of cognitive skills better account for variance in production vs. comprehension of narrative skills for this age range?

Results from the current study indicate that a complex mix of information processing skills was able to account for a significant proportion of variance in narrative abilities in preschool aged children. Additionally, a slightly different package of information processing skills was predictive of narrative comprehension vs. production outcomes. Approximately 40% of the variance in story re-telling (production) abilities was accounted for by a package of information processing skills including some of the most complex executive function tasks included in our assessment battery. Both Card Sorting on post-switch trials and Verbal Fluency contributed a significant amount of unique variance to the final model, and both of these tasks were categorized in Methods as being the most cognitively demanding tasks requiring up to seven distinct processing steps. The observation that children who are better at coordinating the multiple sub-processes on these complex EF tasks are also able to more accurately recall a story’s structure with more complete details suggests that these complex executive function skills may be particularly recruited when constructing a narrative. This becomes especially clear when one considers the multiple processes that an individual juggles when constructing a narrative which include: planning and goal setting (retelling a narrative containing all of the story elements in the correct sequence), retrieval (retrieving the story content as well as grammar indicating causal connections between discrete events), monitoring (paying close attention to local and global coherence of narrative), inhibitory control (inhibiting the more salient “high points” (see Labov, 1972) of the narrative such as the conflict and emotional reactions of the protagonist until
they are appropriate to mention in the unfolding sequence of the retelling) and aspects of
attentional flexibility related to perspective-shifting (orienting the story to the viewpoint of
different characters as they appear in the story). A close parallel can therefore be observed in
terms of the multiple types of executive control processes that support performance on the more
complex EF tasks and narrative production performance.

Some prior empirical work has linked EF skills to theory of mind abilities in preschool
ganged children (Carlson, Moses & Claxton, 2004; Carlson & Moses, 2001; Hughes, 2002),
suggesting an alternative explanation for why the more complex EF skills might be particularly
implicated in narrative abilities. These researchers found that inhibitory control skills (as
assessed by day-night and tapping tasks) and attentional flexibility (as assessed by the Card
Sorting task) were particularly associated with performance on the standard false-belief tasks
used to assess children’s theory of mind abilities. Frye, Zelazo & Palfai (1995) go so far as to
suggest that “advances in children's theory of mind abilities reflect improvement in embedded
rule reasoning that enables children to switch judgments across different settings.” According to
this interpretation, the abilities to maintain different perspectives and suppress an irrelevant
perspective are the crucial EF components supporting theory of mind processes. Tracking
complex narratives also requires understanding and following multiple character perspectives or
mental states and should therefore also recruit the EF component processes that underlie strong
theory of mind. The current results provide some possible support for this interpretation as the
complex EF skills (including attentional flexibility) assessed by the card sorting task emerged as
a significant factor in accounting for substantial variance in narrative production abilities.
However, inhibitory control as assessed by the day-night task did not contribute significant
unique variance to the best fitting model accounting for narrative production abilities. Instead, it
may be that those aspects of inhibitory control essential to narrative performance are better
tapped by the Planning/ Tower of Hanoi task (below) and the two most complex EF tasks in
which inhibition must be patterned together with complex goal management and complex
monitoring.

Other predictors helping to account for variance in narrative production skills included
the following simple EF skills: Tower of Hanoi planning/ goal management abilities and speeded
processing as assessed by a Rapid Naming task. Goal setting, monitoring, and management can
be seen as being important and necessary components for narrative construction. Two possible
strategies have been discussed in relation to successful performance on the Tower task. A goal
recursion strategy (as discussed in Miyake et al., 2000) is expected to involve extensive goal
management and setting up of a series of sub-goals (e.g. If top disc is moved to non-target peg
first, this frees up the second disc which can now be moved to target peg). This strategy is very
demanding as it requires maintenance of multiple sub-goals in working memory. An alternative
strategy that is used more predominantly by younger children is the perceptual strategy in which
moves are made to bring the current configuration of discs perceptually closer to the end goal
configuration. Inhibitory control is especially required when an optimal solution involves
temporarily moving a disc to a location that is further away from the end goal configuration.
Thus, depending on the strategy employed, the Tower task can be considered to tap into goal
management and/or inhibitory control skills (see also Pennington & Ozonoff, 1996). The setting
up of multiple goals, especially the hierarchical embeddings “If this… then do this…” can
especially be seen as being relevant to story organization during story re-telling. For instance,
when children retell a story with multiple episodes (or sequences each containing an initiating
event, problem, attempt, and solution), they must relate each episode back to the main
overarching goal of the story and ultimately resolve the main theme in the story. In other words, in order to tell a coherent story, children need to set up a hierarchical goal structure or mental schema and plan and monitor the organization of the narrative events.

The setting of higher order rules can be more clearly observed in successful performance on the Card Sorting task. Zelazo et al. (2003) in particular describe the necessity of rule embedding in the Card Sorting task, as in this task two rules apply to a single stimulus with respect to different dimensions (e.g. both the rabbit rule and red rule apply to the red rabbit card in different dimensions- i.e. color and shape). Several developmental theories discuss the manner in which children acquire the ability to deal with such representational complexity. Halford and colleagues (e.g. Halford, Wilson & Phillips, 1998) talked about the number of relations that can be processed in parallel as imposing constraints on understanding and mental computations. Their results indicate that only unary relations are processed at a median age of 1 year, binary relations are processed around 2 years, ternary relations are processed at around 5 years and quaternary relations emerge in late childhood/ early adolescence. Relational complexity has further been linked to prefrontal areas in the brain considered to be responsible for higher order executive functioning. For example, in one study, regions of the left prefrontal cortex were differentially activated when solving nonverbal problems high in relational complexity (Kroger et al., 2002). A more explicit link between representational complexity and executive function has been made in Frye, Zelazo and Burack’s (1998) Cognitive Complexity and Control (CCC) Theory. According to this theory, age related changes in executive function are due to age related changes in the maximum complexity of rules that children can formulate and use for problem solving. Complexity in this case refers to the hierarchical structure of rules that can be constructed (or the number of embeddings that can be processed) rather than the number of
relations that can be processed in parallel. On the Card Sorting task, the perseveration shown by some 3-4 year old children on post-switch trials is attributed by this theory to difficulty formulating a higher order rule for selecting between dimensions. Indeed, it has been shown that when rules are not in conflict with one another on this task, then children are able to sort the cards successfully on post-switch trials (Zelazo et al., 2003). Thus, successful performance on the Card Sorting task partly reflects the ability to formulate and monitor a hierarchical structure of rules and to deploy appropriate inhibition—abilities that may also support more successful performance on story construction and re-telling. Similarly, the processing components required in the Verbal Fluency/Complex EF task appear highly relevant to both narrative production and narrative comprehension. For narrative, these include coordination of story schema activations (a parallel process to semantic category activation on the Verbal Fluency task), retrieval of story events and contextual information (parallel to item generation on Verbal fluency), setting the goal of organizing information in a particular sequence that matches canonical narrative structure (similar to goal setting in Verbal fluency for producing category specific exemplars), and tracking and monitoring one’s own production to ensure local and global coherence of the narrative (similar to tracking and monitoring production of items and inhibiting items from other categories or items already generated on the fluency task).

To summarize, narrative production requires the child to set the obvious goal of linking all of the story elements in a coherent manner, retrieving the appropriate semantic information, syntactic structures, and morphological features that would express the causal links between various story elements, and also indicate the characters’ motivations and reactions, and monitor the narrative while it is being produced. And not only do all of these processes need to be coordinated into one coherent system, but they also need to be deployed at incredibly rapid speed.
for coherent production. Thus, in this demanding narrative language production context, it appears that faster speed of processing is advantageous and together with basic planning skills and complex EF skills allows for production of narratives that contain more information organized in the correct sequence.

The package of skills that best predicted narrative comprehension abilities overlapped in 3 out of 4 instances with the set of skills predicting narrative production, including simple EF/planning (Tower of Hanoi) and the two most complex EF tasks. One very highly significant predictor of narrative comprehension, however, was Sentence Completion and Recall/simple EF working memory. This finding is consistent with some prior research showing a listening span tasks that required making plausibility judgments about sentences and then recalling the sentence final words in a particular set helped account for about 8% of unique variance in narrative comprehension abilities in children between the ages of 6 and 11 years (Montgomery et al., 2009). The link between the 4 predictive EF tasks and narrative comprehension may be understood through an elaboration of the specific processes involved in this comprehension task. The comprehension measure consisted of eight questions which required active thinking, reasoning and recall of the story events. For example, two of questions on this measure were “Why did the bus run away?” and “Why did the bus jump over the fence?” Nowhere in the script of the story is it specified what the bus’s reasons/motives were in running away from its driver, although it is mentioned that this bus was naughty. Thus, this particular comprehension question requires integration of pieces of information presented at different points in the story. Similarly, the second question requires the child to recognize and process a cause-effect sequence. In the story, the bus is driving through a country and becomes tired of the road. He then jumps over a fence and races down a hill. Integration of these two sequences is required to correctly identify
the motive for his subsequent action of jumping. Thus, high performance on all aspects of narrative comprehension required active thinking about the sequence of events and consequences of discrete events—including attentional flexibility, inferences, and integration/coordination of just those pieces of information and story structure essential to answering particular questions.

The involvement of higher order complex EF skills in narrative comprehension and production abilities is consistent with the developmental framework posited by Robbie Case on the development of central conceptual structures specific to narrative skills. According to this framework, young children are actively developing a new form of “psycho-logic” between the ages of 4 and 7 years as they integrate rudimentary theory of mind abilities with narrative abilities (Case & Okamoto, 1996). This is purported to be the mechanism which allows them to link story events with character motivations, and tell stories that are goal-based or plan-based and therefore more coherent. The dynamically changing neural architecture, and in particular the formation of long distance connections between the frontal lobes and other lobes in the brain during childhood and through early adolescence, is tied in with this advance in cognitive abilities (Case, 1992; Diamond, 2002; Thatcher, 1992). Specifically, these long distance cortical links are considered to allow for the emergence of more complex executive structures that control these new functions. Thus, based on this prior theoretical and empirical work, it is predicted that preschool children with more complex executive function skills would use these EF skills in supporting the comprehension and production of more complete and more complex narratives.
Question 2. How do multiple information processing skills relate to emerging syntax skills in typically developing children between the ages of 3 ½ and 6 years? Will a different set of cognitive skills better account for variance in production vs. comprehension of syntax skills for this age range?

Syntax production abilities, as assessed by a sentence imitation task, and syntax comprehension abilities, as assessed by a picture matching task on a parallel set of syntactic structures, were both associated with complex packages of information-processing skills that included 3 or 4 Executive Function (EF) measures. Additionally, substantial amounts of variance in syntax abilities were accounted for by phonological working memory skills. The particular mix of information-processing skills that was associated with sentence production was able to account for a considerable amount of variance in syntax production scores –nearly 58%. This mix consisted of simple phonological short-term working memory, 3 simple EF measures and the more complex EF skills associated with Card Sorting and Switching. In term of distinct tasks, the strongest contributors to the best-fitting model included the Nonword Repetition, Forward Digit Span and Card Sorting tasks. The involvement of phonological short term working memory in sentence repetition is not surprising given that this task required children to encode words phonologically and semantically and then hold linguistic information of varying syntactic complexity in memory before repeating it verbatim with appropriate phonological expression. These results are consistent with results by Willis and Gathercole (2001) in which they found that phonological short term memory was related to sentence repetition but not sentence comprehension in 4–5 year old children. What is new and particularly interesting is the predictive ability of the EF tasks in sentence imitation performance. The argument that was made earlier in this paper is that processing complex syntactic structures would implicate not only working
memory resources (e.g., Just & Carpenter, 1992) for keeping multiple possible interpretations open at any given point in the sentence, but also that these alternate interpretations of the sentences may need to be inhibited for successful sentence processing. In line with this argument, both measures of EF inhibition contributed to the model. The involvement of executive resources is apparent upon considering how comprehension of even the most simple sentences requires successful mapping between representations at different levels. More than just memory is required, however: WM representations must be smoothly coordinated with simple EF functions of inhibition and speech assembly/integration/editing processes. As a listener hears a sentence unfolding, they are immediately engaged in the process of stringing syntactic units together to form higher level units. During online processing of sentences, some slots may remain unfilled until the appropriate syntactic units are encountered, leading to the generation of expectancies. Similarly, some syntactic units may remain unattached until their slots are encountered. Thus, the cognitive demands imposed on the system during sentence processing and subsequent production of the assembled sentence also include the complex EF functions of active maintenance of the syntactic units, expectancy generation and updating, coordinated inhibition of inappropriate alternate interpretations, and complex monitoring and complex integration. In the case of reading development and performance, Just & Carpenter (1992) provide an analysis that resonates with our account of individual differences in children’s performance in both syntax and narrative oral language tasks:

“The constraints on every person’s capacity limit the open-ended facets of comprehension, so that a reader or listener cannot generate every possible forward inference, represent every interpretation of every ambiguity, or take into consideration every potentially relevant cue to an interpretation.”
An assumption made by Kutas and King (1996) in their account of syntactic processing fits well with our own dynamic account of how multiple processes are coordinated in real time during sentence processing and production. They suggest that “lexical access, thematic role assignment and construction of discourse representations are interleaved (and occur in parallel) rather than in a sequential manner.” According to this view, partial information is used routinely as it becomes available and may be refined or inhibited as the situation dictates. An example that illustrates these online processes would be the formation of a representation of a simple noun phrase as soon as the words “The boy” are encountered. This syntactic structure may subsequently be refined to a relative clause (in the case of “The boy with the boots…”) or a prepositional phrase (as in “The boy at the desk”) depending on what further information is contained in the target sentence. This computational or probabilistic approach towards language processing is also compatible with the “Competition Model” put forth by Brian MacWhinney (MacWhinney, 2005; Bates & MacWhinney, 1989) according to which multiple cues including stress, intonation, rhythm, morphological marking, and word order are always in competition and interact dynamically every time we hear a sentence. For children whose cognitive resources are still developing and subject to certain constraints, cues that impose an additional load on working memory may be particularly difficult to successfully utilize. For example, in an embedded sentence such as “The boys who received the punishment from the teacher were kept back after school”, registering plurality (of the noun “boys” and verb “were”) as a salient cue would facilitate processing of the embedded clause (“who received the punishment…”). However, holding this plurality cue imposes a load on working memory and so in some contexts (such as sentence repetition) this strategy may only be successful in children who have greater working memory resources. At the same time, these higher working memory resources would be just one
of the multiple enhancers of processing/production along with EF processes. Our results are compatible with this perspective as the children in the present study who were more successful at sentence processing and imitation displayed a stronger package of information processing skills that included three kinds of components: short term phonological working memory, simple EF goal-setting, manipulation, and inhibition resources, and complex EF skills (executive monitoring, selective attention, and coordination resources).

Another syntactic structure that was included in our syntax measures and which may be used to illustrate the way complex EF skills may come into play during sentence processing was the passive structure (e.g. “The dog was washed by the girl”). The active form of this sentence, i.e. “The girl washed the dog”, is the more common syntactic form in English, which typically has sentences following a Subject-Verb-Object (SVO) word order. In order to successfully process the passive structure, children must override word order cues that have been previously learned and consolidated, and focus on the changed grammatical structure introduced by including the preposition “by”. Semantics and pragmatics may also play a role in processing this sentence as it is erroneous to consider the alternative, i.e. dogs do not do washing. Thus, already we have the recruitment of inhibitory control and selective attention, and coordination of these factors with semantics and pragmatics and emerging on-line syntax. Further, all of these must be rapidly coordinated with planning and execution of an assembled sentence.

Given that some children in the current study were likely still in the process of acquiring more complex syntactic structures such as passives, it becomes relevant to discuss the theoretical model for acquisition of syntax put forth by Nelson and colleagues (Nelson, 1989; Nelson, 2000; Nelson et al., 2004). According to the Dynamic Tricky Mix Acquisition Model, children proceed through seven stages of acquisition for passives. In the early stages, only some gestalt or
unanalyzed whole passive structures may be represented in long term memory. However, as children are exposed to more exemplars, they transition into a “hot spot” stage for acquiring passives and begin to establish structural representations of the passive and associated verbs through comparison and contrast of existing structures in their repertoire with new forms and particular instances of each structure. During the sentence imitation task utilized in this study, it is believed that the different levels of abstraction and different concrete instantiations of the passive structure represented in long term memory were likely retrieved for comparison with the passive structures that the children were presented.

The Dynamic Tricky Mix model also provides a framework for the processing of syntactic challenges in general—including, but not restricted to, passive structures. According to this model, numerous network conditions interact dynamically with social and motivational conditions during both language comprehension and production. The network conditions that have been discussed in this model include the parallel activation of multiple pattern abstraction, working memory, retrieval, attention, and EF processes including goal formation and monitoring and coordination/integration processes (Nelson et al., 2004; Nelson & Arkenberg, 2008). The current study results for syntax production/imitation are compatible with this account of how the cognitive system supports processing of syntactic challenges, but goes a step beyond by empirically specifying for 3 ½ to 6 year olds the relation of various simple and complex EF skills to syntactic comprehension and production.

This dynamic account of how the cognitive architecture supports the processing of syntactic structures is also compatible with Bock’s (1982) cognitive model of sentence production. According to Bock, “purely hierarchical formulation systems do not readily accommodate interactions between retrieval or assembly processes and surface syntax…}
sentence production, like other cognitive processes, appears to have both top-down and bottom-up components.” In terms of discrete components or processes, she mentions the involvement of working memory which is proposed to allow for “flexible control of the flow of information from phonetic coding to motor programming.” And although prior research has not investigated the role in children’s language acquisition of an elaborated and differentiated set of EF skills, Chang, Dell and Bock (2006) recognize the importance of “domain-general learning mechanisms such as implicit sequence learning (and connectionist implementations as error-based learning in a simple recurrent network).”

Sentence comprehension was supported by a mix of information processing skills that was fairly similar to those associated with sentence repetition abilities. This mix included two measures of simpler EF resources (TOH and Sentence Completion and Recall) and complex EF skills associated with the Card Sorting task. The two main differences in predictors for comprehension relative to production in this context were that simple phonological working memory by itself did not significantly contribute to performance, nor did inhibition. A processing strategy that aimed at accessing the overall meaning or gist of the sentences would be more useful in this comprehension task compared to a strategy that more heavily involved the phonological loop (cf. Baddeley, 2000) to maintain auditory memory traces and also to prepare for production of the sentences. Accordingly, until sentence gist was extracted, all the various processing steps –including multiple aspects of EF selective attention, monitoring, goal maintenance and coordination– detailed in our discussions above for sentence imitation/production would still hold in this comprehension context.

As regards the significant contribution of two inhibition-heavy measures (Day-Night, Backward Digits) to sentence production but not sentence comprehension, the key contrast may
be that during production of an assembled sentence, inhibition is needed of strong associates to each sentence component and also of later sentence components until appropriate earlier constituents have been expressed by the child.

**Question 3. Will the pattern of predictive relationships between the cognitive variables and language outcomes be similar for simple syntactic structures compared to more complex syntactic structures?**

Results for the syntactic complexity analyses reveal interesting differences in predictive patterns for simple syntactic structures compared to more complex syntactic structures. One key difference is that both production and comprehension of complex syntactic structures draw upon complex EF functions/components, whereas neither production nor comprehension of syntactically simple sentences are predictable from complex EF tasks.

Sentence imitation on the more complex structures recruited the skills underlying the more complex EF tasks. The best fitting model predicting complex sentence imitation included both the phonological short term working memory tasks, the simple EF/ Backward Digits and simple EF/ Tower tasks, and both of the complex EF tasks. The structures that were considered to be complex included those with two types of clauses. An example of a complex syntactic structure would be a combined relative clause and coordinated conjunction (“If the boy with the tie finishes studying, then he can watch TV”). Processing these more complex sentences would require the coordination of attention to multiple arguments, and would be expected to place significant demands on working memory, inhibitory control, integration, and monitoring processes. In fact, for many of the children in the current study who are still in the process of acquiring these more complex structures, it is expected that active comparisons with already
consolidated structural descriptions of these syntactic structures would be taking place in parallel (see discussion of the Dynamic Tricky Mix model of language acquisition in previous section).

It has been observed in prior empirical work examining children’s natural production of syntactic structures that children under 3 years of age tend to avoid producing relative clause constructions that contain more than a single proposition (Diessel & Tomasello, 2000). A limited processing capacity at this age has been used to account for these findings, which is in line with other developmental accounts for syntax acquisition posited by Newport (1990) and Elman (1993). Both researchers argue that processing limitations give rise to the incremental developmental pattern observed wherein children proceed from simple to more complex structures (cf. Slobin, 1985; Elman et al., 1996). Bates, Dale, and Thal (1995) have shown using simulations based on connectionist models that “grammatical generalizations (i.e. rulelike behaviors) do not arise until the system has acquired enough instances to support those generalizations. When the requisite number of items has been acquired, dramatic (nonlinear) changes (are observed to) take place, even within a single system.”

For children in the current study, it is very likely that children were at various stages in the acquisition of the more complex syntactic structures, and that individual differences in current performance on the syntax measures reflect important individual differences in how quickly children over many months and years had been progressing in this domain. Similarly, it is assumed that those cognitive processing components most predictive of syntactic processing are also those cognitive processing components most influential in the children's gradual progress in syntax over many months and many learning opportunities preceding the current assessments.
Referring back to the Cognitive Complexity and Control (CCC) theory by Zelazo and colleagues (1998; 2003), the processing of these more complex syntactic structures further requires building a hierarchical representation or a representation with embedded structures. And based on the CCC, this type of processing relies heavily on EF networks. Thus, it is not surprising that performance on this subset of more complex structures was predicted by a model including the most complex EF tasks.

Sentence imitation abilities on the simpler structures (1/2 the total sentence set) recruited simple goal setting and monitoring/updating EF resources underlying Sentence Completion and Recall performance, simple EF inhibitory control skills related to the Day-Night task, and two phonological working memory tasks. The role of working memory and inhibitory control in the processing and repetition of these simple structures is apparent when one considers the types of structures used on this task. Examples of structures classified as “simple” syntactic structures included prepositional phrases (“The doll is on the box”) and final embedded relative clauses (“The teacher watches the child who is sleeping”). In order to successfully imitate these two different structures, the child needs to keep track of multiple arguments/local dependencies. In the first example, the child needs to process the information about location contained in the preposition, i.e. the doll is on the box and not under or inside it. In the second example, the child needs to process and integrate two pieces of information: the teacher is watching the child, and the child is sleeping. Thus, in order to form a complete and accurate representation of the sentences that then guide the child’s imitative productions, the child not only needs to hold extracted constituents in working memory but also actively integrate them and inhibit alternate representations. This interpretation is in line with Bock’s (1982) conceptual model of sentence imitation in which immediate recall is not considered to simply be the emptying of a short-term
store but instead utilizes production mechanisms to assemble highly activated linguistic units. A prediction that naturally follows this conceptual argument is that simple EF skills would be recruited to coordinate these activated linguistic units into the correct overall sentence production.

In contrast to the sentence imitation results described above, syntax comprehension was not shown to be related to phonological short term working memory for either level of complexity. These results are consistent with the proposal set forth by Marten and colleagues (Hanten & Marten, 2000) that unlike sentence repetition that relies more heavily on conceptual and phonological representations, sentence comprehension instead depends more upon access to temporary semantic representations. Comprehension performance on the simple structures was only predicted by the simple EF planning skills related to the Tower task. Additionally, these simple EF skills only accounted for 13% of the variance in comprehension abilities unlike the 32 - 58% of variance explained by the other multiple-predictor models for syntactic complexity outcomes. Consistent with the pattern obtained for imitation, comprehension of more complex syntactic structures was related to more complex EF skills as assessed by the Card Sorting task.

Very few prior studies have examined EF processes in relation to production and comprehension performance on syntactic structures ranging in terms of complexity in young children. One limitation in the couple of studies that have looked at processing of simple vs. complex syntactic structures is they focus only on sentence comprehension abilities but do not draw comparisons with production abilities (Montgomery et al., 2008; Montgomery & Evans, 2009) Another limitation of this prior research is the inclusion of only a couple of tasks designed to assess EF processes. For example, processing speed and attentional allocation to dual tasks were the only EF functions examined in relation to sentence comprehension abilities in one study.
(Montgomery et al., 2008). Both tasks were able to account for a significant amount of variance in complex sentence comprehension abilities (including passives and reflexives), but not for simple comprehension abilities in 6-12 year olds. However, the relative contribution of more complex EF functions was not assessed in this sample of children. In another study, Montgomery and Evans (2009) examined the contribution of phonological working memory and attentional allocation to dual processes via a listening span task to the comprehension of complex sentences and simple sentences in typically developing 4.5 to 8 year olds. Again, they found that the EF functions associated with the attentional allocation task accounted for unique variance in complex sentence comprehension but not simple sentence comprehension. Consistent with our results (and also Willis & Gathercole, 2001), sentence comprehension did not seem to be significantly associated with phonological working memory skills. Furthermore, the ability of the listening span task to account for a substantial amount of variance in complex syntax comprehension abilities (31% of variance was accounted in the Montgomery et al., 2008 study) is also consistent with our results which implicate the simple EF skills associated with a Sentence Completion and Recall task with overall syntax comprehension abilities in young children. However, this simple EF task is not included in our final model for complex syntax comprehension and instead the more complex EF processes associated with the Card Sorting and Switching task better accounts for variance in comprehension abilities in this more challenging context. This finding highlights the importance of including a range of tasks that tap into more complex EF processes when examining the cognitive skills linked to the processing of more complex aspects of language.

The neuroimaging literature provides much evidence that garden path sentences and more complex sentences are integrated later around 500-1000 ms or later (as indexed by
neurophysiological measures such as ERPs) compared to relatively early and automatic processes such as detecting word category information (Is this unit a noun phrase?), feature checking (Is the word inflected correctly?) and conceptual-lexical integration (Hahne & Friederici, 1999; Kutas & Federmeier, 2000; Osterhout & Holcomb, 1992). A relatively recent study (Clegg, Lau & Kuperberg, 2011) found that the P600 component associated with syntactic processing was modulated by syntactic conflict experienced on previous trials. They interpret this finding as providing evidence for the P600 reflecting a more general executive control process of monitoring. The flexible and rapid involvement of general executive control process in syntactic processing, especially in response to detecting and resolving conflict between competing representations, has been proposed by other researchers as well including January, Trueswell & Thompson-Schill (2009) and Novick et al. (2005). It is speculated that the association found between the more complex EF skills subserving the Card Sorting and Switching task and the comprehension of more complex syntactic structures by young children reflects the recruitment of similar cognitive control neural substrates and processes as referenced in this developmental neuroimaging literature.
Question 4. How do multiple information processing skills relate to emerging vocabulary skills in typically developing children between the ages of 3 ½ and 6 years? Will a different set of cognitive skills better account for variance in production vs. comprehension of vocabulary skills for this age range?

Results from this study suggest that a more complex package of information processing skills is involved in vocabulary comprehension and production than indicated by the prior literature. Previous research has emphasized phonologic short term working memory as being particularly important in the early stages of vocabulary acquisition (Baddeley et al., 1998; 2003) and correlations have indeed been observed between the Nonword Repetition task and vocabulary skills in preschoolers (Gathercole, 2006). However, it should be pointed out that these correlations have not been consistently observed across different studies and across children of different ages. Additionally, no prior study has examined the relative contributions of a differentiated set of information processing skill components in relation to vocabulary outcomes.

We find that a model including three simple EF tasks, including the Day-night task, Tower planning task and Sentence Completion Recall task – but no phonological working memory task– accounts for a significant amount of variance in both vocabulary comprehension and production in preschoolers. Overall, the pattern of predictors as well as order of contributions made by individual predictors in explaining variance is quite similar for comprehension and production; the only exception being that the simple EF Backward Digit Span also emerged as a significant predictor in the model for vocabulary production abilities. Thus, it appears that simple EF skills assessing aspects of inhibitory control, planning,
monitoring, and goal management are associated with 3 ½ -to- 6 year-olds’ performance on these receptive and productive vocabulary measures.

The similarity in patterns for how the cognitive tasks relate to vocabulary comprehension and production can be explained upon consideration of the processes underlying performance in these two contexts. Naming a picture and pointing to the correct picture after hearing its name both involve activation of a semantic network and impose demands on working memory. Picture naming requires retrieval of the appropriate label and may require some inhibitory control as competing labels that share semantic and/or phonological features may become activated in parallel (Dell, Chang & Griffin, 1999; Schwartz, Dell, Martin, Gahl & Sobel, 2006). Similarly, accessing the conceptual representation upon hearing a lexical item may require some inhibition of items that share lexical-semantic information with the target word. Compared to the complexity of goals and monitoring for narrative and sentence contexts, these vocabulary tasks are simpler. Nevertheless, the pattern of results for vocabulary indicates that relatively simple aspects of Executive Function come into play. These EF components are, in addition to inhibition, simple goal setting and maintenance (simply matching pictorial information to lexical items), and simple monitoring.

An aspect of EF, namely the ability to inhibit competing representations, has been discussed in relation to speech planning and production within a single language. According to Green and Abutelabi (2013), “competing representations may extend over the entire speech pipeline from formulating the message, selecting and sequencing relevant lemmas and word forms, to retrieving, and articulating relevant phonemes and monitoring self-produced speech with respect to its predicted acoustic/phonetic form.” Thus, at least for speech production, a case
has been made for the involvement of EF processes associated with inhibitory control being relevant.

Aspects of inhibitory control seem to furthermore be implicated in task performance on all of the cognitive measures that emerged as being relevant for vocabulary abilities in the current study. The Day-night task requires inhibition of the a pre-potent response (saying “day” to the cards depicting day and “night” to the cards depicting nighttime), the Tower task requires inhibition of the perceptual strategy (i.e. moving discs so that they look similar to the end goal configuration without considering essential counter-intuitive intermittent steps), the Sentence Completion Recall task requires inhibition of non-targets words in sentences and target words from previous trials, and the Backward Digit Span task requires inhibition of the prepotent response of repeating the original sequence of digits without reversal. Other processes in common among all of these EF measures include goal setting and goal monitoring which appear to be relevant for both vocabulary comprehension and production contexts as well.

Few studies have examined the contributions of EF skills to vocabulary in young children. Only one study (Wolfe & Bell, 2009) to date has examined and shown a significant relation between inhibitory control skills as assessed by the Day-night task and vocabulary skills in preschool aged children. However, it should be noted that only receptive vocabulary skills were measured in that study so the relative contribution of inhibitory control as assessed by the Day-night task among a larger set of EF measures had not been assessed for both vocabulary comprehension and production abilities prior to this study.

Contrary to predictions, phonological short term working memory did not contribute significantly to either vocabulary comprehension or production in young children. Furthermore, the correlations between the two phonological working memory measures and vocabulary skills
across the 3 ½ to 6 year age range were found to be small, ranging from $r=.12$ (ns) to $r=.32$.

These results indicate that phonological working memory may not be as much of a constraining factor for vocabulary acquisition as previously thought. Many theoretical variations on dynamic processes (Sporns, 2011; Nelson et al., 2004; Nelson & Arkenberg, 2008; Miyake & Shah, 1999; Elman et al., 1996) could accommodate the present vocabulary results as a demonstration that the functions of phonological working memory emerge during vocabulary production or comprehension within an overall set of dynamic processes tapped better by EF tasks than by phonological memory alone. If viewed from this perspective, then our results suggest that the prior literature has overemphasized phonological short term working memory and overlooked the importance of a combination of simple EF skills including relatively simple aspects of planning, inhibitory control, goal management, monitoring, and selective attention as critical contributors to vocabulary acquisition and performance.
General Discussion

The results and discussion of the present study provide some new and fundamental insights into the ways that multiple cognitive processes feed into the acquisition and use of language by young children between the ages of 3 ½ and 6 years. For the first time in the field we see a direct comparison of the relative contributions of a large, differentiated set of cognitive predictors to the production and comprehension of three domains of young children's language: narrative, syntax, and vocabulary.

Cognitive Skills and Narrative Development

In the case of narrative production, we interpret the results to indicate that higher levels of narrative skill draw upon a package of complex cognitive skills that are coordinated dynamically in real-time as the narrative unfolds. This package most notably includes for both narrative comprehension and narrative production the complex EF skills recruited by a card sorting and switching task (the DCCS) and by a spontaneous semantic category production task (Verbal Fluency), as well as relatively simple EF planning and goal monitoring abilities tapped by the Tower of Hanoi. These results are consistent with our discussion of the various steps involved in narrative comprehension and production, including the setting up of a hierarchical goal structure or story schema, and planning, organizing, and monitoring the organization of the various elements in the story.

Additionally, minor differences were observed in which information processing skills related to story comprehension vs. production. Story comprehension performance was additionally predicted by simple EF updating and goal monitoring, whereas the predictive model for story production included speeded processing abilities in addition to the 3 common predictors.
summarized above. These differential patterns can readily be explained when considering the demands that these two different narrative contexts impose on a child. The story comprehension task required children to recall specific plot points and contextual information from a story that had been previously read out to them and to make inferences about these discrete events. Successful performance on this task would be greatly supported by greater updating and goal monitoring resources in combination with the more complex EF skills of attentional flexibility and coordination/integration. The story generation context on the other hand requires even greater coordination of multiple processes such as real-time retrieval and maintenance of story grammar structures, lexical items, and syntactic structures along with attentional flexibility, inhibition, and monitoring. In this latter case, greater processing speed would facilitate performance by allowing the child to free up and deploy the cognitive resources required for successful performance on this highly complex task.

Prior literature is quite sparse about such relationships between cognition and children’s narrative development, but Karmiloff-Smith (1986, 2001) has some findings that are of relevance. In her work she demonstrated that when young children between the ages of 5 and 7 years were edging into slightly more advanced levels of narrative production they often showed temporary regressions in the levels of syntactical and lexical sophistication of their narratives. She accounts for this developmental pattern by suggesting that children are re-organizing their approach towards how narratives should be structured from a more bottom-up approach (with a greater focus on discrete components) to a more top-down approach (with a greater focus on global structure and coherence). The final stage in this developmental model is successful integration of both sentence-level and narrative-level structure but this stage is typically not attained until late childhood. Given that the children in the present study fall within the age range
where they are actively negotiating the transition into the second stage of narrative development, it is expected that higher order EF skills will be recruited quite heavily. Indeed our data do suggest that both narrative production and comprehension recruit a skill package that includes skills sampled by the two most complex EF tasks. Zelazo’s (2003) Cognitive Complexity and Control (CCC) Theory can also help account for these results. According to this theory, as well as that proposed by Halford and colleagues (Halford, Wilson & Phillips, 1998), children at this age are advancing in terms of the maximum complexity of rules that they can formulate and use for problem solving. This ability to form and manage hierarchical goal structures to solve problems is considered to be tapped by the complex EF Card Sorting and Switching task and the complex EF category fluency task.

It is also important to consider the information processing components that were not shown to account for substantial variance in narrative abilities and account for these findings. Certain component processes such as inhibitory control, as measured separately by the Day-night task, and phonological short term working memory were not found to account for significant variance in narrative abilities. However, this does not necessarily indicate that these processes are not involved in narrative comprehension and/or production, as they may be considered to be integrated within the complex set of processes measured by the more complex EF tasks. This account of more complex EF skills emerging and incorporating dynamic coordination of simpler processes is in line with multiple accounts of emerging dynamics within cognitive systems (Miyake & Shah, 1999; Nelson et al., 2006; Thelen & Smith, 2006; Sporns, 2011). According to Miyake and Shah (1999), higher order executive control and regulation is an emergent property that results from dynamic interactions within subsystems. Sporns (2011) also recognizes this complex coordination of distributed neural resources and argues that “functions do not reside in
individual brain regions but are accomplished by network interactions that rapidly reconfigure, resulting in dynamic changes of neural context” and that “the same pattern of regional activations can be brought about by multiple distinct patterns of dynamic relationships.” Diamond’s (2012) conceptualization of EF is also consistent with these perspectives and she describes EF as a family of control functions with some core functions that work together to form higher-order EF processes such as reasoning, planning and decision making. In line with these accounts of the emergence of higher order EF processes from more basic component processes, it may be argued that the more complex EF processes incorporate aspects of phonological short term working memory and inhibition when appropriate and timely and that these are coordinated with the other higher order processes of monitoring, retrieval, attentional flexibility, goal management, integration and planning.

**Cognitive Skills and Syntax Development**

In the case of complex syntax production and complex syntax comprehension, we similarly interpret the results to indicate that higher levels of syntax draw upon a package of complex cognitive skills coordinated dynamically in real-time. This package contrasts somewhat with that just described for children's narrative skills. It includes the more complex EF skills underlying switching performance on the card sorting task which were also recruited in narrative tasks. However, in addition to these skills, complex syntax production and complex syntax comprehension both tap into simple EF abilities of updating and goal management as measured by Sentence Completion and Recall. Production relative to comprehension further employed the complex executive skills recruited by a semantic fluency task, as well as simple EF planning/manipulation (Tower task, Backward Digit task) abilities and phonological short term working memory. Prior literature has occasionally gone into some interesting depth about such
relationships between multiples aspects of cognitive processes and children's developmental progress in syntax. A series of papers by Nelson and colleagues (Nelson et al., 2004; Nelson & Arkenberg, 2008) address how acquisition of new syntactic structures by children depends upon the dynamic coordination of timely retrieval of stored lexical and syntactic structures, maintenance in working memory of new sentences carrying syntactic challenges, inhibition of prepotent sentence interpretation, comparison in working memory of the new sentences to retrieved structures in the child's repertoire, abstraction of syntax new to the child and storage of such new abstractions into long-term memory. Completing all these related steps in less than a minute requires, on this account, rapid deployment of EF goal-setting (try to abstract new syntax) with continuous monitoring of progress toward that goal. For the children in the present study presented with complex sentences for comprehension or for production/imitation, we argue that their immediate performance as well as their developmental past history leading to their current levels of syntax sophistication involves an analogous set of coordinated cognitive processes. Analyses combining children’s sentence production performance on complex and simple sentences structures yield a very similar picture suggesting the involvement of a rich mix of switching abilities, inhibitory control, monitoring, updating, and phonological short term working memory.

In contrast, when children’s performance for simple sentences is analyzed separately, the more complex EF skills no longer help account for substantial variance. Sentence production is now best accounted for by individual differences in phonological short term working memory and inhibitory control along with updating and goal management and monitoring, whereas sentence comprehension only significantly related to simple EF planning abilities.
Thus, our results for 3 ½ to 6-year-olds’ sentence performance reveal important differences in syntax production vs. comprehension, with phonological short term working memory only showing strong links to production. The results further suggest that more complex EF skills are recruited differentially for processing of more complex syntactic structures.

**Cognitive Skills and Vocabulary Development**

Vocabulary skills were found to be related to a more complex mix of information processing skills than discussed in the prior literature. Prior empirical work examining the link between information processing resources and vocabulary skills has failed to take into account multiple aspects of EF and include these in regression models predicting receptive and productive vocabulary outcomes in preschoolers. Thus, the contribution of tasks assessing multiple aspects of EF has never been pitted against the relative contributions of phonological short term working memory—which has been emphasized as being particularly important in young children’s vocabulary acquisition (e.g. Gathercole, 2006). Our results indicate that in fact a package of simple EF skills including updating and goal management, planning, monitoring, and inhibitory control are relevant for vocabulary production and comprehension and account for about 40% of variance in these scores. These results are in line with models of speech recognition and production that recognize the dynamic nature of interactions between competing representations at the conceptual, lexical and phonological levels whenever words are accessed and retrieved (e.g. Bock, 1982; Dell et al., 1999).

**Conclusions**

The current study is novel in its attempt to examine how a differentiated set of cognitive functions including both simple and complex EF skills contribute to different domains of
language in young children. The research to date on how cognitive skills relate to language acquisition and performance has only looked at a few EF processes in relation to narrative, syntax, and vocabulary acquisition and performance. A consequence, likely due to this narrow approach, has been that only limited amounts of variance in language abilities (rarely exceeding 30%) have been explained by EF functions. The current study demonstrates that large and substantial amounts of variance (32-58%) in language performance across different domains can be accounted for by cognitive skills when a large and differentiated set of cognitive functions are examined.

The current study results also shed light on the complexity of EF processes and how they pattern together to support language in young children. The construct of “executive function” has been an especially hard construct to pin down with consensus and has been discussed in relation to a wide variety of cognitive functions. According to Miyake and Shah (1999), EF has three distinct components, namely inhibition, updating, and cognitive flexibility. Zelazo, Muller, Frye & Marcovich (2003) on the other hand discusses executive function as a functional construct enabling a higher level of consciousness and the ability to formulate increasingly complex higher level rules. He also makes a distinction in his work between “hot” aspects of executive function associated with regulation of limbic system processes and more “cool” aspects of executive function associated with the dorsolateral prefrontal cortex. In other related writing, Zelazo and colleagues see EF as inclusive of problem representation, planning, execution, and evaluation functions (Zelazo, Carter, Reznick, & Frye, 1997). Diamond (2002) has a slightly different method still of classifying EF processes and discusses this in terms of the functions linked to complex neural circuits in which the prefrontal cortex play a major role. She identifies the following four cognitive functions as EF processes: (1) speed of processing, (2) the ability to use
strategies, (3) holding information in memory and manipulating or transforming it, and (4) maintaining information in the face of interference. Pennington and colleagues similarly incorporate multiple cognitive functions in their concept of EF: goal setting and management, planning, organized retrieval, speeded processing, hypothesis testing, and inhibition (Pennington & Ozonoff, 1996; Roberts & Pennington, 1996; Welsh et al., 1991). There is also inconsistency in how working memory (a construct typically subsumed within the construct of EF) is defined and employed in the literature. Some researchers define working memory as requiring both a storage and manipulation function (e.g. Baddeley, 2000) whereas others discuss working memory in terms of active maintenance of select information while inhibiting irrelevant information (Conway & Engle, 1994).

Despite this past inconsistency in how working memory or other EF functions are described, it is generally acknowledged in the literature that finding a pure process task measuring only one aspect of EF is virtually impossible. The current study attempts to circumvent this issue by organizing tasks in terms of the number and complexity of component processes that are sampled by the tasks and seeing how these differentially relate to language abilities across different modalities (comprehension vs. production) and across different domains (vocabulary vs. syntax vs. narrative). We also know that the prefrontal cortex displays a protracted course of development (e.g. Huttenlocker, 1990) and that this is likely to have important consequences on children’s performance on tasks requiring coordination of higher order EF processes. The developing prefrontal cortex is expected to place constraints on the kinds of higher order EF processes that children can reliably recruit during acquisition and performance. However, for those children who are better able to coordinate and deploy higher order EF functions, it is expected that they will in turn demonstrate higher levels of performance
on both the complex EF tasks and complex language tasks. It is also assumed (as is often the case in the language acquisition literature) that individual differences in performance on language tasks will reflect important differences in how children have been progressing in their language abilities in the many months preceding their assessment. Similarly, it is assumed that the cognitive processing components that are most predictive of current language performance in any given domain are also those cognitive processing components that are most influential in the children’s gradual progress in the language domains over the many months and many learning opportunities preceding the current assessments. Future longitudinal work will need to be conducted to identify in additional ways the cognitive processing patterns that most strongly support the learning of new language structures. Future work could profitably use the framework of the present study to explore for younger children, at 1 to 3 years of age, which patterns of cognitive functions contribute most strongly to children's progress in language learning. Nonetheless, the current study does provide some valuable insight into how particular subsets of cognitive processes may have contributed to individual differences in the paces of children’s acquisition in the domains of vocabulary, syntax, and narrative.

The current study results are also informative for current cognitive models of language processing and acquisition. Connectionist and other emergentist accounts of language development acknowledge the contribution of cognitive processes to the acquisition and use of language structures. However, few models of language development clearly specify the roles of individual cognitive component processes to specific language domains. According to a dynamic systems framework (Nelson et al. 2004; Nelson et al., 2008), multiple conditions cooperate and converge to support language processing and learning and performance. These include social and motivational processes which interact with children’s current cognitive skills to facilitate
learning. The cognitive processes that have been elaborated upon in the Dynamic Tricky Mix model of language acquisition include attentional engagement, organization of strategies, rapid parallel retrieval, pattern abstraction, planning, monitoring and editing of plans. The current study goes a step further in showing which of these processes—as sampled by a set of phonological memory and EF tasks—differentially support vocabulary abilities, syntactic abilities across a set of sentences ranging in syntactic complexity, and narrative abilities. Thus, in addition to acknowledging the importance of all of these cognitive processes to language acquisition, the current study isolates the particular patterns of contributions of phonological WM, simple EF processes, and more complex EF processes to 3½ to 6-year-olds’ language skills in each of the different language domains.

One limitation of the current study is that the sample size does not permit the use of certain sophisticated statistical analyses such as structural equation modeling (SEM) that would help test the predicted causal relationships between the cognitive variables and language variables. Future research should employ both confirmatory factor analysis and SEM to test and validate our conceptualization of simple and complex EF processes and how the various cognitive variables relate to language processing across the different domains in young children.

One concern that is often raised with multivariate regression is multicollinearity, or high degrees of correlation among predictor variables possibly resulting in a redundant set of predictor variables in the final model. In the current analyses, multicollinearity diagnostics were examined for all regression analyses and both the Tolerance indicator as well as the Variance Inflation Factor (VIF) showed that multicollinearity was not an issue. This conclusion is also supported by the small to medium size of intercorrelations among the cognitive predictor variables (see Appendix).
Results from the present study hold important implications for language remediation strategies for young children. A handful of studies have attempted to train discrete components of EF such as working memory (e.g. Klingberg et al., 2005), reasoning (Bergman Nutley et al., 2011), and inhibitory control (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). However, a shortcoming of this training work that has been widely acknowledge is the lack of generalization of learning to different tasks purportedly assessing the same EF component, as well as the lack of transfer to other cognitive skills or to language skills. Based on our results, we would advocate training children with language delays on tasks that incorporate multiple aspects of simple and complex EF functions as these appear to be recruited in language performance across a variety of domains. This recommendation is consistent with some empirical work showing that training on a task switching task (complex EF task) transferred to both an untrained switching task as well as tasks measuring inhibitory control, nonverbal and verbal working memory and reasoning (Karbach & Kray, 2009). This approach is also in line with Diamond’s (2012) perspective on EF training which is to avoid narrowly focusing on a single cognitive component, but to instead choose training activities that are engaging and rewarding and target multiple components of EF and require focus, discipline, holding complex sequences in working memory and quick and flexible adaptation to changed circumstances.

In summary, the current study is innovative in using a wide variety of cognitive tasks sampling a range of phonological WM and EF processes and relating these to performance across three different language domains in young children between the ages of 3 ½ and 6 years. Moreover, the current study is unique in examining how both comprehension and production across the language domains of vocabulary, syntax and narrative differentially recruit this set of cognitive processing skills. Results reveal the involvement of a combination of processes tapped
by the more complex EF tasks for narrative comprehension and production and for the
comprehension and production of more complex syntactic structures. Another conclusion is that
the results for vocabulary are somewhat inconsistent with the prior literature and suggest that a
more complex mix of cognitive processing skills may be involved in word recognition and
production than previously thought. Overall, the study results highlight the importance of
examining a diverse set of complex cognitive functions in relation to language processing and
acquisition even in young children who sometimes are argued to have limited control over higher
order EF processes.
References


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Appendix: Inter-correlations between the cognitive predictor variables.

<table>
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<tr>
<th></th>
<th>Nonword Repetition</th>
<th>Forward Digit Span</th>
<th>Processing Speed</th>
<th>Inhibition Day-Night</th>
<th>Backward Digit Span</th>
<th>Tower of Hanoi-Planning</th>
<th>Sentence Completion Recall-Span</th>
<th>Card Sorting &amp; Switching</th>
<th>Verbal Fluency</th>
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<tr>
<td>Forward Digit Span</td>
<td>.285**</td>
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<tr>
<td>Processing Speed</td>
<td>-.243*</td>
<td>-.203</td>
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<tr>
<td>Inhibition Day-Night</td>
<td>.205</td>
<td>.069</td>
<td>-.169</td>
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<tr>
<td>Backward Digit Span</td>
<td>.321**</td>
<td>.251*</td>
<td>-.499**</td>
<td>.195</td>
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<tr>
<td>Tower of Hanoi-Planning</td>
<td>.339**</td>
<td>.281</td>
<td>-.274*</td>
<td>.185</td>
<td>.280**</td>
<td></td>
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<tr>
<td>Sentence Completion Recall-Span</td>
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<td>.123</td>
<td>-.464**</td>
<td>.039</td>
<td>.452**</td>
<td>.255*</td>
<td></td>
<td></td>
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<tr>
<td>Card Sorting &amp; Switching</td>
<td>.199</td>
<td>.183</td>
<td>-.273*</td>
<td>.195</td>
<td>.250*</td>
<td>.401**</td>
<td>.457**</td>
<td></td>
<td></td>
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<tr>
<td>Verbal Fluency</td>
<td>.236*</td>
<td>.122</td>
<td>-.465**</td>
<td>.275*</td>
<td>.441*</td>
<td>.340**</td>
<td>.507**</td>
<td>.378**</td>
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Note: * p<.05, ** p<.01
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Selected Presentations  

