Language and Executive Function in Preschoolers

by

Emanuela Yeung
B.Sc. (Hons), University of Toronto, 2007

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Supervisory Committee

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Abstract

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Based on classic and contemporary theories of cognitive development by Vygotsky, Luria, and Zelazo and colleagues, the main objective of the present study was to systematically evaluate the association between different aspects of language, namely semantic and syntactic knowledge, and specific executive functioning (EF) abilities (working memory, inhibition, and flexibility) in preschoolers. Sixty-seven children age 3-5 years were administered a battery of EF and language measures. A latent variable approach was used to estimate performance on EF tasks. A two-factor model consisting of working memory/inhibition (WM/INH) and flexibility provided the best fit for the data. The results showed that syntactic ability uniquely explained a significant amount of variance in both WM/INH and flexibility over and above age and semantic ability. Furthermore, children's complex syntax scores predicted their performance on complex blocks of flexibility tasks. These findings provide preliminary evidence for the association between children's understanding of the structure of language and EF.

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Introduction

Executive function (EF) is broadly defined as the higher-order cognitive processes underlying the conscious control of thought and behaviour (Zelazo & Müller, 2010). Although there is little consensus regarding the specific processes that constitute EF, most researchers agree that they include working memory, set shifting or cognitive flexibility, and response or inhibitory control (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Garon, Bryson, & Smith, 2008). Developmental changes in EF have been well documented and these abilities are thought to emerge during the first year of a child's life (Jacques & Marcovitch, 2010). EF continues to develop into adulthood, with important and rapid changes occurring between 3 and 5 years of age. EF is related to social understanding, school readiness, and academic achievement (Perner & Lang, 1999; Müller, Liebermann, Frye, & Zelazo, 2008), and impairments in EF have been implicated in developmental disorders such as autism spectrum disorder (Russell, 1997) and attention-deficit/hyperactivity disorder (Schachar, Mota, Logan, Tannock, & Klim, 2000). However, despite these advances in our understanding of EF, little is known about the psychological processes that promote the development of EF and the specific mechanisms by means of which they do.

The Role of Language in the Development of EF

Vygotsky and Luria

One area of research has examined the development of language as a possible mechanism contributing to the development of EF (see Müller, Jacques, Brocki, & Zelazo, 2009 for a review). Much of this work is based on the early theories of cognitive development by Lev Vygotsky and Alexander Luria. In Vygotsky's theory, socio-cultural tools such a language play an important role in the emergence of higher cognitive abilities, including self-regulation.

According to Vygotsky, children regulate and control their behaviour using sign systems, such as speech, a process called semiotic mediation. Initially, external signs (e.g., speech sounds) function as stimuli that direct a child's attention (Vygotsky & Luria, 1994). Through the process of internalization, speech first used in this communicative context (e.g., directives) becomes directed inward (as inner speech) and is applied by the child to him/herself to organize his/her behaviour (Vygotsky, 1986).

Focusing on the semantic aspect of self-directed speech, Luria (1959) found that the ability to effectively regulate behaviour emerges during the preschool period as children became able to use the meaning of self-directed speech to control their actions. For example, in examining the effects of labels on performance on a Go/No-Go inhibition task, Luria found that children's ability to use increasingly complex verbal commands to guide their behaviour developed with age. In this task, children were asked to press a button when a red light came on (go trials) and refrain from pressing when a blue light turned on (no-go trials). In this basic version of the task, younger children (around 3 years of age) had difficulty inhibiting their response during the no-go trials, while older preschoolers tended to perform well. However, when 3-year-olds were asked to accompany their motor behaviour (i.e., pushing the button) on the go trials with verbal, self-directed commands (i.e., saying "press"), they were able to effectively control their behaviour by pressing and not pressing the button in response to the appropriate signal (Luria, 1959). The same pattern was not observed for the no-go trials; when 3-year-old children were asked to say "don't press" when the blue light lit up, they failed to inhibit their motor response, and in fact pressed the button even harder. Luria (1959) reasoned that initially, words lack meaning for the young child and have a non-specific excitatory response. Each individual word elicits an orienting response and the child reacts by pushing the button without considering the presentation of the light signal. This response is appropriate when the verbal command accompanies the ‘go’ stimulus, however, it is inappropriate during no-go trials. It is not until children are approximately 4 to 5 years of age that they are able to successfully use verbal labels to respond appropriately in this task.

Contemporary Approaches to Studying the Relation between Language and EF

Contemporary research has examined the relation between language and EF using cross-sectional or longitudinal correlational studies, and experimental manipulations assessing the effect of labeling on children’s performance on tasks designed to measure EF. Attempts to replicate Luria’s findings have yielded mixed results (see Diaz, 1992 & Flavell, 1977 for reviews), although there is some evidence supporting the association between inner speech and performance on shifting tasks (see Cragg & Nation, 2010 for a review).

Recent studies have primarily examined the effect of labels using the Dimensional Change Card Sort (DCCS), a widely used measure of flexibility and rule-use (Zelazo, 2006). In the standard version of this task, children are presented with 2 target cards (e.g., a picture of a red rabbit and blue boat) and asked to sort a set of bivalent test cards (e.g., blue rabbits and red boats) according to a specific dimension (e.g., shape) during a “pre-switch phase”. After sorting according to the first dimension, children are asked to switch and sort according to a new dimension (e.g., colour) during the “post-switch phase”. Results from numerous studies have shown that the majority of 3 year olds continue to sort according to the pre-switch rule or dimension during the post-switch phase, despite being told the rules on each trial and correctly answering questions about the post-switch rules (see Zelazo, Müller, Frye, & Marcovitch, 2003 for a review). Studies investigating the effect of labeling on children’s performance during the post-switch phase have yielded mixed results. In one of the first studies to examine this potential effect, Kirkham, Cruess, & Diamond (2003) found that 3-year-olds performed significantly better on post-switch trials when they were asked to label the relevant sorting dimension on each trial, compared to peers in the basic condition of the task. In a similar vein, Yerys & Munakata (2006) found that removing relevant linguistic information and using an uninformative label to describe the sorting rule during the pre-switch phase (i.e., “these go here” instead of “the red one goes here”) resulted in more children correctly sorting according to the post-switch rule, compared to children in the basic version of the task.

Both Kirkham et al. (2003) and Yerys & Munakata (2006) provide bottom-up explanations regarding how language or labeling facilitates flexibility or switching in the DCCS. According to Kirkham et al.’s (2003) attentional inertia theory, children perseverate during the post-switch phase because they are unable to switch their attention to the new, relevant dimension. Labeling this dimension allows children to redirect their attention from the more salient pre-switch dimension to the new one. Language, according to this theory, acts as a mediational device by facilitating inhibitory control and altering the child’s attentional bias. In Yerys & Munakata’s (2006) representational competing systems model, labels help to strengthen active representations of currently relevant information such that it “overcomes” strong latent representations of the prepotent response. Removing an informative label weakens the strength of what will be the latent representation, such that during the post-switch phase, the new active representation is strong enough to overcome the latent trace, leading to correct sorting and flexible behaviour.

Cognitive Complexity and Control Theory-Revised

In contrast, others have suggested that language may play a top-down role in facilitating flexible behaviour by providing a child with a more complex rule structure (e.g., Happaney &

Zelazo, 2003; Müller et al., 2009) or by generating more abstract relations between items (Gentner & Loewenstein, 2002). Specifically, Zelazo and colleagues have proposed that language may have both a constitutive and an executive function in the conscious control of behaviour (Müller et al., 2009), based on their Cognitive Complexity and Control theory-Revised (CCC-r; Zelazo & Jacques, 1996; Zelazo & Frye, 1998; Zelazo et al., 2003). According to this theory, developmental changes in EF are due to changes in the maximum complexity of rules that a child can formulate and use when solving problems. These rules link antecedent conditions to consequences, such as when we say to ourselves, "If I see a mailbox, then I need to mail this letter", and complexity of rules increases when there are multiple levels of embedded rules (e.g., If it is before 5 P.M., then if I see a mailbox, then I will mail this letter). Increases in the complexity of rule systems results in more flexible behaviour due to increased options in the selection of rules for acting when conflicting choices are possible. This is illustrated in Figure 1, in which rule A links antecedent 1 (a1) to consequent 1 (c1), and is incompatible with rule B that links a different antecedent 2 (a2) to consequent 2 (c2). Flexible behaviour results from the formation of a higher-order rule (rule E), which links the situations (s1 and s2) under which the different sets of rules are appropriate. For example, in the DCCS (see Figure 2), children are taught two sets of rules for sorting (i.e., the rules for sorting by shape, and the rules for sorting by colour). Perseveration during the post-switch phase results from the inability to form a higher-order rule that serves as a relation between the two sets of sorting rules (i.e., if we are playing the shape game, and if it is a rabbit, it goes there; however, if we are playing the colour game, and if it is red, it goes there). Consequently, children who continue to sort according to the pre-switch rule during the post-switch phase, despite being able to articulate the post-switch sorting rule, do so because they are unable to represent the contrastive relation between them. According to

CCC-r theory, it is only when a child is able to formulate this higher-order representation of the contrastive relation between sets of rules, that flexible shifting behaviour is possible. The role of language in the development of flexibility is in facilitating reflection and the emergence of these higher-order relational and hierarchically embedded representations (Zelazo & Jacques, 1996; Müller et al., 2009).

To test whether labels facilitate performance on flexibility tasks in this top-down manner, Müller et al. (2008) conducted a series of experiments that examined the effect of labeling on different versions of the DCCS. They stipulated that if labeling does generate a more complex conceptual structure, the effects should generalize and children should exhibit shifting behaviour even with new stimuli. However, if labeling has a bottom-up effect as Kirkham et al. (2003) and Yerys & Munakata (2006) have suggested, flexibility of responses may be linked to specific stimuli. Müller et al. (2008) were unable to replicate Kirkham et al.'s (2003) previous findings or show a benefit of labeling under different conditions. A more recent labeling study by Doebel & Zelazo (2013) replicated and extended Kirkham et al.'s (2003) study, finding that labeling the stimuli in the relevant dimension did promote switching behaviour, although irrelevant labels did not hinder performance in a symmetrical manner. An additional study by Jacques, Zelazo, Lourenco, & Sutherland (2006) using the Flexible Item Selection Task (FIST) has also shown that labeling can facilitate flexible behaviour in 4-year-olds.

In the standard version of the FIST, children are shown three items (e.g., a small *red* boat, a small *red shoe*, and a small blue *shoe*). Two of the objects match on one dimension (e.g., the red ones match on colour), and two items match on another dimension (e.g., the shoes match on shape). One *pivot* item always matches on each dimension. During each trial, children are asked to select a pair of cards that "go together in one way" (i.e., Selection 1) and then asked to select a pair of cards that "go together but in another way" (i.e., Selection 2). Selection 1 responses measure the child's ability to identify how two non-identical items match on one dimension, while Selection 2 responses (assuming successful performance of Selection 1) measures the child's ability to flexibly switch between dimensions. Results have shown that 4-year-olds generally perform well on Selection 1 but significantly worse than 5-year-olds on Selection 2 (Jacques & Zelazo, 2001). However, when 4-year-olds were asked to label the dimension of their first selection, their performance on Selection 2 was significantly better than the performance of 4-year-olds in the standard version of the task or of those asked to label an irrelevant dimension (Jacques, et al., 2006). These results are incompatible with a bottom-up explanation as such an approach would predict poorer performance on Selection 2 of the task after labeling a salient dimension during Selection 1.

The findings from these labeling studies provide some support for the suggestion that language plays a role in the emergence of inhibition and cognitive flexibility. Moreover, recent longitudinal studies have found verbal ability to mediate the relationship between parent scaffolding at age 2 and children's EF abilities at age 4 (Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone, 2011) and significantly predict the development of executive functioning in the preschool years (Fuhs & Day, 2011; cf. Hughes, Ensor, Wilson, & Graham, 2010).

The Potential Role of Syntax in the Development of EF

Interestingly, however, these studies have not examined the contribution of one important aspect of language, namely syntax or the structure of language, to the development of EF. When examining the relation between language and EF, researchers have generally used tests such as the Peabody Picture Vocabulary Test (PPVT) or language subscales of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) as indices of “verbal ability”. These scales largely focus on the semantic aspect of language by evaluating a child’s expressive or receptive vocabulary. There have not been any studies (to my knowledge) that have evaluated children’s syntactic knowledge specifically, and its relation to EF. This is surprising given that in the domain of social reasoning, which is highly correlated with the development of EF (see Moses & Tahiroglu, 2010), researchers have documented that children’s comprehension of a specific kind of complex syntax may be a prerequisite for the understanding of false beliefs (e.g., de Villiers & de Villiers, 2000; de Villiers & Pyers, 2002; Lohmann & Tomasello, 2003; cf. Slade & Ruffman, 2005). For example, de Villiers and colleagues have suggested that understanding the complementation syntax of mental verbs, in which a sentence takes a full clause as its object complement (e.g., Dave thought *it was raining outside*) is a necessary precursor to the development of theory of mind. Furthermore, training studies have demonstrated a robust causal relation between syntactic understanding and the development of false belief understanding (Lohmann & Tomasello, 2003).

Theoretically, there is also reason to believe that mastery of complex syntax may contribute to the development of EF. Although Luria’s empirical studies focused on the designating function of words, he also recognized the importance of the morphological characteristic of words (or structure of language more generally) in organizing one’s experience of the world:

> Each word actually classifies the content being designated by it, transmitting a total human experience to the listener or the speaker and abstracting complex systems of ties and relationships from the real world. The external form of the word itself is a powerful means of systematizing experience. (Luria, 1999, p. 95)

Moreover, Luria suggested that the system of relations imbued in the meaning and syntactic characteristic of words is thought to underlie flexible thinking, by allowing the child to separate speech from the immediate context and form more complex and abstract connections:

> …the word preserves in itself all systems of connections in it, beginning with the very elementary and visual and ending with the very complex and abstract. Depending on the task, any one of the systems of connections can become dominant. Without this ability, flexible thinking is impossible. (Luria, 1999, p. 98)

Werner and Kaplan (1963) have also suggested that the acquisition of syntax plays a crucial role in the coordination of thoughts and the forming of complex relations between thoughts, and an analogous process of coordinating rules and forming higher-order relations is also proposed to underlie the development of flexibility in Zelazo et al.'s CCC-r theory discussed previously.

According to the CCC-r theory, developmental changes in EF are related to the maximum complexity of rules that can be represented by a child. Rule complexity is explicitly defined as an increase in the number of hierarchically embedded rules or clauses, which is an increase in the syntactic complexity of a rule. Thus, it would be expected that the ability to process more complex syntactic rules, specifically hierarchically embedded subordinate clauses, facilitates the development of EF. In a Vygotskian manner, children's comprehension of complex syntax first used in a communicative context (e.g., embedded subordinate clauses such as "after it rains there's puddles") may become internalized into self-directed speech, which ultimately may underlie the development of flexible, goal-directed behaviour.

The Present Study

The main objective of the present study is to systematically evaluate the association between different aspects of language, namely semantic and syntactic knowledge, and specific EF abilities (working memory, inhibition, and flexibility) in preschoolers using a latent variable approach. The advantage of this approach is that it allows for the examination of a priori relations between factors, and controls for measurement error by extracting only the common variance shared by different tasks that are specified to measure the same latent factor (Bryant & Yarnold, 1994; Klem, 2000). The preschool period is also a time in which EF abilities undergo rapid and dramatic changes (Jacques & Marcovitch, 2010).

Although previous studies using confirmatory factor analysis (CFA) have generally found unitary (Wiebe, Espy, & Charak, 2008; Wiebe et al., 2011; Hughes, et al., 2010; Fuhs & Day, 2011; Visu-Petra, Cheie, Benga, & Miclea, 2012) or 2-factor working memory and inhibition solutions (Miller, Giesbrecht, Müller, McInerney, & Kerns, 2012) to best fit the data in preschoolers, a more complex EF structure should not be ruled out as task and performance indicator selection can influence the latent factor structure (Miller et al., 2012). In many of the previous CFA studies, measures of flexibility or set shifting have not been included (Wiebe et al., 2008; Wiebe et al., 2011; Hughes et al., 2010). In the study by Miller et al. (2012), measures of set shifting or flexibility were found to load significantly on the working memory factor in the preferred model, though they suggest that this finding is due to overlap in the shared variance between these tasks.

Given that CFA results can vary depending on task selection and parameter estimates, the present study will use different measures of flexibility to clarify the latent factor structure of EF in preschoolers by comparing 5 a priori competing models (see Figure 3). I hypothesize that a 3-

factor model with working memory, inhibition, and flexibility latent factors will best fit the data. Multiple regression analyses will then be used to examine the contribution of different aspects of children's language ability, namely semantic and syntactic knowledge, to the three latent EF variables. Although the association between semantic knowledge and executive functioning has been well established, I hypothesize that syntactic knowledge will have a significant unique contribution to flexibility and working memory over and above the contribution of semantic knowledge and age. Based on the CCC-r theory of EF development, I do not expect inhibition to be uniquely associated with complex syntactic knowledge as the development of this construct can be explained based on understanding of a "simple" if-then rule structure (e.g., "If red then press; if blue don't press" in Luria's Go/No-Go task).

A secondary aim of the present study is to test the specific relation between syntactic or structural complexity and rule complexity in the CCC-r theory, as measured by set shifting or flexibility tasks. Given that the ability to represent complex, higher order rules is thought to underlie the development of flexibility, one might expect comprehension of complex syntax to be uniquely associated with more complex blocks or trials within EF tasks. For example, in the DCCS, one might expect specific knowledge/comprehension of more complex syntax to facilitate performance during the post-switch phase, but not during the pre-switch phase. To test this idea, a series of multiple regression analyses will be conducted, in which performance on complex blocks of flexibility tasks will be regressed on measures of complex syntax knowledge, with the simple blocks of those EF tasks partialled out.

Method

Participants

Participants were 67 children (*M* age = 51 months, *SD* = 7.25 months, range = 36 – 66 months; 34 males, 33 females) recruited from preschools and daycares in the Greater Victoria Area. An additional 7 children participated but were not included in the analyses due to failure to complete greater than 50% of the tasks because of scheduling constraints (*n* = 6) or refusal to participate during 1 or more testing sessions (*n* = 1). The majority of the sample was Caucasian and came from two-parent families (97%). The median maternal and paternal education of the sample was 4 years of post-secondary education, and the median annual household income was $80-110,000 CAD.

Materials

The Go/No-Go task was administered on a 14” touchscreen laptop. All testing sessions were either video or audio recorded for subsequent transcription and coding.

Measures

Cognitive Flexibility EF Tasks

EF Scale for Preschoolers (EFSP). The EFSP (Carlson, 2012) is a measure of children’s rule use and cognitive flexibility, based on the DCCS. Similar to the DCCS, children were asked to sort test cards into boxes labeled with target cards, however, the task begins with less complex sorting rules (i.e., single sorting rules during the pre- and post-switch phases) and gradually becomes more complex at each additional level (i.e., pairs of sorting rules). The scale consists of 7 levels, with Levels 1-4 each consisting of a pre- and post-switch phase with 5 trials per phase. Levels 5-7 each consist of 10 trials, and children are asked to switch between rules in a pseudo-random order across these trials. For the purposes of the current study, each child began at Level 3 and continued to the next level until they reached their ceiling level.

In Level 3, children were asked to sort test cards that only match target cards on one dimension (i.e., target cards are a black flower on a yellow background, and a black heart on a pink background; test cards are black hearts on yellow backgrounds, and black flowers on pink backgrounds). In the pre-switch phase, children were asked to play the shape game, where they matched the cards based on the shape of the black image. In the post-switch phase, children were asked to play the colour game, where they must ignore the shape and instead focus on the coloured background of the card. Level 4 is most similar to the standard version of the DCCS. In this level, the dimensions of shape and colour are integrated in the same image, with target cards being a blue star on a white background, and a red truck on a white background. The test cards have blue trucks on white backgrounds and red stars on white background, which match the target cards on only one dimension. In the pre-switch phase, children were asked to play the colour game, and then asked to switch to the shape game. Level 5 used the same target cards as Level 4, however, children were shown that they can play either the shape game ore the colour game. The examiner held up a card and said either, “Play the shape game”, or “Play the colour game”, and children had to flexibly switch between games. In Levels 6 and 7, the same target cards as Levels 4 and 5 were used, however, some of the test cards had borders around them. Children were told that the presence or absence of a black border indicated which sorting rule was relevant for that particular card (e.g., “If there is a black border, you have to play the shape game; if there is no black border, you have to play the colour game”).

To pass a level, the child had to successfully complete 4 out of 5 trials on both the pre- and post-switch phases for Levels 3 and 4, and correctly sort 4 out of 5 shape and colour or 4 out of 5 border and no border trials. The ceiling level is the highest level where the child fails 2 or more of the 5 trials during either the pre-switch or post-switch phase for Levels 1-4, or fails to sort 2 or more of the 5 trials of the shape/colour or border/no border rule for Levels 5-7. The task was discontinued when a child failed to pass a level. Children were given a score for the highest level passed.

Flexible Item Selection Task (FIST). The FIST (Jacques & Zelazo, 2001) is a measure of EF that focuses on the specific component of cognitive flexibility. During each trial of the task, children were shown 3 cards depicting different objects (e.g., a small *red* boat, a small *red shoe*, and a small blue *shoe*). Two objects matched on one relevant dimension (e.g., the red ones match on colour), and 2 items matched on another dimension (e.g., the shoes match on shape). One *pivot* item always matched on each dimension. A third dimension (e.g., size) remained constant across all three items. During each trial, the child was asked to select a pair of cards that "go together in one way" (i.e., Selection 1) and then asked to select a pair of cards that "go together but in another way" (i.e., Selection 2). Selection 1 responses measure the child's ability to identify how two non-identical items match on one dimension, while Selection 2 responses (assuming successful performance of Selection 1) measures the child's ability to switch between dimensions. Children were presented with 9 test trials, and the number of correct selections were scored for both Selection 1 and Selection 2.

Shape Game. The Shape Game is an adapted version of the Shape School (Espy, 1997). In this task, children were presented with a storybook depicting character-like shapes of varying colour. The task has 2 blocks: Control and Switch, with the latter condition considered to be measures of flexibility. All children received the Control block first, and the Switch block second. In the Control block, children were asked to name of the colour of the figures, in order, as quickly as possible, without making any errors. In the Switch block, some of the figures wear glasses and the others do not. Children were asked to name the shape of the figures with glasses, and the colour of figures without glasses. There were15 figures in each block, and children were a score based on efficiency ((the number of correct – the number of errors)/ total time).

Inhibition EF Tasks

Head-Toes-Knees-Shoulders (HTKS). The HTKS task is measure of behavioural regulation or motor response inhibition (Ponitz, McClelland, Matthews, & Morrison, 2009). Children were asked to play a game where they were instructed to touch their heads and then touch their toes. After four practice tests, in which the child becomes habituated to the verbal instructions, he/she was then asked to respond in the opposite way for 10 trials (e.g., if the experimenters says "touch your toes", the correct response is for the child to touch his or her head). In the next 10 trials, two more commands were added; when the experimenter says, "touch your knees", the child was instructed to touch his/her shoulder and vice versa. A score of 2 was given for correct responses, 0 was given for incorrect responses, and 1 point was given if the child made any motion to the incorrect response but self-corrected and ended with the correct action. Commands were given in a consistent, non-random order. For the purposes of the present study, and to limit working memory demands, children's performance on the first 10 trials were scored.

Go/No-Go. In the computerized version of the Go/No-Go (Kerns & McInerney, 2007), the child was instructed to push a computer button in response to the appearance of target stimuli and refrain from responding (pushing the button) to the appearance of non-target stimuli. The task was divided into 1 baseline block and 3 test blocks. Each block consisted of 25 stimuli and lasted for approximately 45s. In the baseline block a prepotent response to push the button in response to a specific target stimulus (a dog) was established. In the first test block, the child was introduced to a new target stimulus (a koala) and asked to push the button for the koala, but refrain from pressing for the dog. In the second test block, the child was asked to push the button for the dog, and in the third test block, to respond to the koala. Performance was measured in terms of inhibition with the number of commission errors (i.e., responding to non-target stimuli) during test block 1.

Luria's Tapping Test. In the Tapping Test (Diamond & Taylor, 1996) children were instructed to immediately tap twice using a wooden dowel after the experimenter tapped once, and to tap once if the experimenter tapped twice. A series of 16 trials were presented in pseudorandom order and no feedback was given during each trial. Performance was measured using the number of correct responses.

Working Memory EF Tasks

Backward Digit and Backward Word Spans. In the Backward Span tasks (Davis & Pratt, 1995), children were asked to recall a series of single-digit, non-sequential numbers (Digit Span) and single-syllable, non-semantically related words (Word Span). The task began with a two-digit or two-word practical trial in which corrective feedback was provided as need. If children were unsuccessful after two repetitions of the practice trial, the task ended, and they were given a score of zero. Children who passed the practice trials received two trials each of two-, three-, and four-digit or word lengths. The tasks were discontinued when children made errors on two trials of the same length. Performance is measured with the highest digit or word length completed.

Self-Ordered Pointing task. In the Self-Ordered Pointing task (Hongwanishkul, Happaney, Lee, & Zelazo, 2005), children are presented with sets of pictures and asked to point to pictures they had no yet chosen in. In the demonstration trial, children are first shown a sheet with 2 pictures and asked to choose one, after which the page is turned and a new sheet depicting the same to pictures in different locations is shown. Children are then asked to point to a picture they had not yet selected.

The test trials are presented in the same manner as the demonstration trial beginning with 3 pictures. The number of pictures per set increases by 1 (up to a maximum of 10) until the child errs on 2 consecutive trials (i.e., if the child points to the same picture twice). Children are given a score for the highest number of pictures in the last trial set on which they are correct.

Language Measures

Measures of Receptive and Expressive Semantics

Peabody Picture Vocabulary Test, 4th edition (PPVT). The PPVT is a measure of receptive vocabulary (Dunn & Dunn, 2007). In this test, the child is presented with a book with 4 pictures on each page. During each trial, the child hears a world and is asked to point to the picture on the page that corresponds to that word. The test is discontinued when the child makes an error on 8 out of 12 sets of words. Children were given a score for the highest set completed.

Expressive Vocabulary (CELF-EV) and Recalling Sentences (CELF-RS) subtests form the Preschool Clinical Evaluation of Language Fundamentals (CELF). The Expressive Vocabulary and Recalling Sentences subtests of the CELF (Wiig, Secord, & Semel, 2004) were used as measures of expressive semantics.

In Expressive Vocabulary subtest, the child was asked to name the object or describe what was happening in a series of standardized pictures using single words, phrases, or complete sentences. There were 20 trials in total and children received a score of 0, 1, or 2 on each trial according to standardized criteria. The task was discontinued when 7 consecutive errors were made.

In the Recalling Sentences subtest, the child was asked to imitate a series of sentences of varying length and complexity presented by the experimenter. There were 15 trials in total. Children were given a score of 3 if they made no errors, a score of 2 if they made 1 error, a score of 1 if they made 2 or 3 errors, and a score of 0 if they made greater than 3 errors. The task was discontinued when children received a score of 0 on 3 consecutive trials.

Measures of Receptive and Expressive Syntax

Word Structure subtest from the Preschool CELF (WS-CELF). The Word Structure subtest from the CELF (Wiig, Secord, & Semel, 2004) was used as a measure of expressive syntax, as it measures children’s understanding of grammatical rules in a sentence-completion task. In this task, the child was asked to complete a sentence presented by the experimenter that was related to an illustration. There were 24 trials in total and children received a score of 1 for each correct response. The task was discontinued when 7 consecutive errors were made.

Index of Productive Syntax (IPSyn). The IPSyn (Scarborough, 1990) is a measure of the expression of syntactically complex forms utilized by a child. A transcript for each child was derived from a 10 minute “warm up” play session with the experimenter, as well as spontaneous utterances during each testing session. The first 100 utterances were coded for 56 morphological and syntactic items on 4 subscales: 1) noun phrases 2) verb phrases, 3) questions/negations, and 4) sentence structure. A total score is computed by summing the points awarded for each item.

For the purposes of the present study, 2 scores will be examined: 1) the total IPSyn score and 2) the score on the sentence structure subscale.

Word Order Test (WOT). The Word Order Test (Slade & Ruffman, 2005) is a measure of children’s syntactic understanding of word order. In this test, children were shown a book with 4 pictures on each page, and asked to point to a picture described using a sentence that included order syntax (e.g., "point to *the bird is chasing the dragonfly*" when shown pictures of a bird chasing a dragonfly, a dragonfly chasing a bird, a bird and dragonfly standing next to each other, and a bird and dragonfly facing each other). To successfully select the correct picture, it is necessary for the child to understand the sequence of the words "bird" and "dragonfly" in the sentence, in addition to the individual meaning of the words themselves (semantic knowledge). . Children were presented with 10 items and given a score based on the number of correct items.

Embedded Clause Test (ECT). The Embedded Cause Test (Slade & Ruffman, 2005) is a measure of children's understanding of centre-embedded clauses. In this test, children were shown a book with 4 pictures on each page, and asked to point to a picture that was described using an embedded clause (e.g., "point to *the square that is under the shoe is red"* when shown pictures of a red square under a white shoe, a red show above a white square, a white square above a red shoe, and a white shoe under a red square). To successfully select the correct picture, a child must understand the syntax of the sentence, or the embedding of the clause as it relates to the main clause of the sentence. Children were presented with 10 items and given a score based on the number of correct items.

Procedure

Participants were tested individually at their daycare or preschool, in a separate room or quiet area to minimize distraction for the participant and other children. Parents provided informed written consent and oral assent was obtained from the child before each testing session. All tasks were administered in English. Children received several small gifts (i.e., stickers) for their participation during each session.

Participants were tested across 2 (n = 28), 3 (n = 37), or 4 (n = 2) sessions according to the preference of the child or preschool supervisor. Each session lasted approximately 20-45 minutes. The median amount of time between sessions was 16 days. The task order for all participants was: Executive Function Scale for Preschoolers, Backward Word Span, Heads-Toes-Knees-Shoulders, Peabody Picture Vocabulary Test-4, Flexible Item Selection Task, Tapping Test, Word Order Test, Shape Game, Embedded Clause Test, Self-Ordered Pointing, the Word Structure, Expressive Vocabulary, and Recalling Sentences subscales from the Clinical Evaluation of Language Fundamentals, Backward Digit Span, and the Go/No-Go. A fixed task order was chosen in order to separate tasks with similar cognitive demands and facilitate comparisons between tasks (see Carlson & Moses, 2001 for further justification).

Results

Data Preparation

All variables were screened for univariate and multivariate outliers, and for skewness and kurtosis. One outlier was found for Go/No-Go commission errors, CELF word structure, and IPSyn total score. These outlier values were replaced with the highest remaining score plus/minus one under the assumption that the children's true scores were extreme on these tasks. Mahalanobis distance did not reveal any multivariate outliers after the changes to univariate outliers were made.

Table 1 displays the skewness and kurtosis for all variables. The IPSyn total score was negatively skewed and leptokurtic, and the Go/No-Go commission errors were positively skewed and leptokurtic. The Word Structure subscale of the CELF and the EFSP were also leptokurtic, while the Backward Span tasks, HTKS, and TT were platykurtic. A review of the video files showed that the children seemed to understand and were engaged in the tasks. As such, no score transformations were conducted. All other variables were reasonably normally distributed (i.e., standard scores of skewness and kurtosis below 2).

Descriptive Statistics

Table 1 displays the descriptive statistics for all the variables. There were no significant differences in performance on any tasks between boys and girls. Variations in task sample size were due to equipment malfunction (n = 6), unable to administer the task due to time constraints (n = 9) and child's refusal to complete the task (n = 2). In total, 2% of the data were missing. A subset of the missing data is considered missing not at random; data missed due to time constraints (n = 9) were for a specific task that was at administered at the end of a particular testing session, based on a predetermined task order (see above). To avoid sample size reduction in the case of listwise deletion, the missing values were imputed using expectation maximization in SPSS 21.0.

Zero-order correlations between all variables are displayed in Table 2. For ease of interpretation, the Go/No-Go block 1 commission errors were reverse scored in order to correspond to the other variables that were scored in terms of correct responses. There were significant correlations among all the language measures and EF measures, as well as between most language and EF measures. All language and EF measures other than the ECT and SOP were significantly correlated with age.

Age-partialled correlations between all variables are shown in Table 3. Correlations among most language measures remained significant, while many correlations among the EF measures were no longer significant after controlling for age. The correlations between the BDS, HTKS and most language measures as well as the correlations between the PPVT-4 and most EF tasks remained significant.

Factor Structure of EF

The aim of the present study was to examine the association between language and EF in preschoolers using a latent variable approach. First, five confirmatory factor analyses (CFAs) were conducted to estimate and compare models of EF latent structure based on findings from previous CFA studies.

Confirmatory Factor Analyses

Based on the covariance matrix of the manifest EF variables, Amos 18.0 (Arbuckle, 2009) was used to fit all models with full information likelihood estimation. To scale each model for estimation, a single manifest variable was fixed to load at 1.00 for each latent factor. The error variances for all estimated models were uncorrelated.

Model fit was evaluated using the chi-square goodness-of-fit test (Loehlin, 1998), chi-square/degrees-of-freedom (Bollen, 1989), the comparative fit index (CFI; Bentler, 1990), and the root mean square error of approximation (RMSEA; Steiger, 1990). Good model fit was associated with a low chi-square value, chi-square/degrees-of-freedom ≤ 3, a CFI $\geq .95$, and a RMSEA $\leq .06$ (Kline, 2005). Nested model comparisons were evaluated using the chi-square difference test. If two nested models fit the observed data equally well, the simpler model was preferred when comparison to a more complex model did not differ significantly at $p \leq .05$ (Bollen, 1989). Model comparisons also were evaluated using Akaike's information criterion (AIC; Bozdogan, 2000), which penalizes more complex models by accounting for the number of estimated model parameters. Lower AIC values represented better model fit (Kline, 2005).

The specific EF models tested (see Figure 3) included a single-factor model in which all the indicators loaded onto a unitary EF factor (Model 1), a pair of two-factor models with working memory and inhibition factors in which flexibility indicators either loaded on the inhibition factor (Model 2) or working memory factor (Model 3), a two-factor model with flexibility and working memory/inhibition (WM/INH) factors (Model 4), and a three-factor model with flexibility, working memory, and inhibition factors (Model 5). The model fit indices (see Table 4) indicated that Models 1 and 4 provided a good fit to the observed data. However, the covariance matrices for Models 2, 3, and 5 were not positive definite, which meant that the factor solutions for these models were inadmissible (Arbuckle, 2009); this was most likely due to an inflated correlation between the working memory and inhibition factors ($r > 1.00$, $p < .001$) in all 3 models.

Model modifications were performed after post-hoc evaluation of the parameter estimates by dropping the SOP and Go/No-Go manifest variables, which had low factor loadings (i.e., ß <.50) in both Model 1 and 4. These modified models (Models 1a and 4a; see Figure 4) were reestimated to see whether they resulted in a better fitting and more parsimonious model. Model fit indices (see Table 4) show that each model provided good fit of the data; moreover, model comparison using the AIC suggested that the modified models were a better fit than the unmodified models.

A model comparison between the modified unitary and two-factor model were conducted to determine the best-fitting model. The chi-square difference between Model 1a and 4a indicated that Model 4a fit the observed data significantly better than Model 1a, and Model 4a also had a lower AIC value than Model 1a. As a result, Model 4a was preferred over Model 1a. The estimates for this model are displayed in Table 5; the correlation between WM/INH and flexibility factors was significant (r = .80 in Model 4a, p < .01).

The Association between Different Aspects of Language and EF

Data Reduction

Although there were high correlations observed among all language measures, separate aggregate measures of syntactic and semantic ability were created in order to evaluate the unique contribution of both aspects of language to EF. To create a measure of syntax, the scores on the WOT, ECT, CELF-WS, and IPSyn were standardized and summed. To create a Semantics Score, the scores on the PPVT-4, CELF-EV, and CELF-RS were standardized and summed. Principal components analysis confirmed that the individual measures included in the syntax aggregate score yielded one component, which explained 53% of the total variance. Similarly, principal components analysis showed that 3 measures included in the semantics aggregate score yielded a single component, which explained 70% of the total variance. The zero-order and age-partialled correlations between the syntax and semantics aggregate measures were $r = .65$ and $r = .62$, respectively ($p < .001$). Both syntax and semantics aggregate measures were also significantly correlated with age ($r = .28$, $p < .05$, and $r = .60$, $p < .001$, respectively). The zero-order and age-partialled correlations between the language measures, aggregate language scores, and EF factors derived from the CFA analysis are displayed in Tables 6 and 7.

Multiple Regression

Two hierarchical regression analyses were conducted to examine the relation between syntactic and semantic ability and different aspects of EF (WM/INH and flexibility). Tables 8 and 9 summarize the analysis that explored the relation between syntactic and semantic ability and the WM/INH and flexibility factor scores derived from the CFA of Model 4a. The analyses showed that syntactic ability uniquely explained a significant amount of variance in both

WM/INH and flexibility over and above age and semantic ability. Semantic ability also uniquely explained a significant proportion of variance in flexibility, but not in WM/INH.

The Relation between Syntactic Complexity and Rule Complexity

A hierarchical regression analysis was conducted to examine the relation between syntactic complexity and rule complexity in measures of flexibility. First, an aggregate measure of "simple" rule use was created by summing the standardized scores of 1) Level 3 performance on the EFSP, 2) the efficiency score on the control block of the Shape Game, and 3) the number of correct first selections of the FIST. Similarly, an aggregate measure of "complex" rule use was created by summing the standardized scores of 1) Level 4-7 performance on the EFSP, 2) the efficiency score on the Switch block of the Shape Game, and 3) the number of correct second selections on the FIST. Finally, an aggregate measure of syntactic complexity was created by summing scores on the ECT, WOT, and sentence structure subscale of the IPSyn. The correlations between these aggregate measures and age are displayed in Table 10.

To examine the unique contribution of syntactic complexity to rule complexity, complex rule use was regressed on syntactic complexity, controlling for simple rule use. The results showed that complex syntax scores significantly predicted performance on the complex blocks of flexibility tasks (b=.22, $t(63) = 2.27$, $p < .05$). Complex syntax also explained a significant proportion of variance in complex flexibility scores ($R^2 = .49$, $F(1, 60) = 5.14$, $p < .05$). After also controlling for age, these effects became marginally significant (p = .07).

Discussion

The aim of the present study was to systematically evaluate the relation between different aspects of language (namely syntax and semantics) and executive functioning using a latent variable approach. Based on the measurement parameters included in the study, it was hypothesized that a three-factor model of executive functioning would best fit the observed data. With regards to the relation between language and EF, it was hypothesized that syntactic ability would uniquely account for a significant proportion of variance in working memory and flexibility performance, over and above age and semantic ability. Semantic ability was predicted to be related to all 3 aspects of EF, based on previous findings in the literature. The pertinent findings will be discussed below.

Latent Structure of EF in preschoolers

Based on previous CFA studies that have examined the factor structure of EF during the preschool period (e.g., Miller et al., 2012; Wiebe et al., 2008; Wiebe et al., 2011) and the performance indicators included in the present study, I hypothesized that a three-factor model with distinct but correlated inhibition, working memory, and flexibility factors would best fit the observed data. Contrary to this hypothesis and previous findings, a 2-factor model with separate but highly correlated working memory/inhibition (WM/INH) and flexibility factors was found to be the best fit.

As Miller et al. (2012) discuss, the findings from CFA studies are largely influenced by the task and performance indicators included in the analysis, and CFA studies that have found a unitary structure of EF have generally not included measures of flexibility. For example, Wiebe et al. (2008) included 3 tasks chosen a priori to measure working memory and 7 measures of motor or cognitive inhibition, and did not estimate any models that included set-shifting/flexibility factor. Thus, in some sense the findings from our CFA are consistent with these unitary models, as the measures of working memory and inhibition were indeed found to load on the same factor. Moreover, a unitary factor structure was found to be a good fit for our data according to the model fit indices, though the two-factor model was more parsimonious and provided a significantly better fit.

To date, only one other CFA study has found a two-factor latent structure of EF in preschoolers. The model with the best fit in the study by Miller et al. (2012) included separate but correlated inhibition and working memory factors with measures of flexibility loading with the measures of working memory. One possible reason for the different pattern of results may be the different working memory and inhibitory control measures included in our analysis. Our WM/INH measures included 2 backward span tasks and 2 motor inhibition measures. By contrast, the study by Miller et al. (2012) included 4 measures of working memory and 4 cognitive and motor inhibition tasks. Performance on these measures was highly correlated and this was also reflected in the not positive definite covariance matrix in CFA models where separate inhibition and working memory factors were estimated.

These patterns of high correlation could be due to a number of factors. Firstly, although we tried to limit the working memory demands in our inhibitory control measures (i.e., by including tasks with only ‘simple’ or few instructions), we did not remind children of these rules during each trial of the task. Thus, it is possible that children who performed better on the inhibition tasks did so because they were better able to recall and act according to the rules of the task. Secondly, as Wiebe et al. (2008) suggest, it is possible that the unitary WM/INH factor reflects a developing inhibitory process in young children, as well as the common task requirement to identify and attend to the correct stimulus-response relationship.

The separate flexibility factor in our best-fitting model is inconsistent with previous CFA studies. As discussed earlier, the presence of this factor may be due to the inclusion of these measures in our analysis[1]. Although Miller et al. (2012) included measures of flexibility, they were found to load with the working memory factor. It was suggested that the high correlation between the flexibility and working memory measures was due to the high working memory demands in their flexibility tasks (the DCCS, and later blocks of the Go/No-Go). We included two flexibility tasks (the EFSP and Shape Game) that have not previously been included in CFAs[2], which arguably have higher shifting demands. For example, in the FIST, children are required to shift their categorization of the stimuli (i.e., shape, colour, size) after each selection, and rapid shifts occur trial-to-trial in both the Shape Game and the higher levels of the EFSP. By contrast, the shifts between rules in the Go/No-Go occur between each block (which consist of 25 “trials” or presentation of stimuli).

It should be noted that the results of our CFA should be evaluated with caution due to the small sample size in our study. Although we believe that the not positive definite covariance matrices in 3 of our proposed models resulted from a high correlation between the working memory and inhibition measures, is it possible that they reflect an insufficient sample size (MacCallum, Widaman, Zhang, & Hong, 1999). Because the primary aim of the CFA analyses in the present study was to create “purer” measures of EF by circumventing the task impurity problem (Miyake et al., 2000), and not to evaluate the latent factor structure of EF per se, I think it is reasonable to assume that the model fit indices in the best fitting model reflect a truly good fit of the model to our data, despite the discrepancies from previous CFA studies.

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[1] The CFA study by Fuhs & Day (2010) also included measures of set-shifting. However, the interpretation of their multi-factor CFAs was limited due to half of their manifest variables (3 of 6) not loading on any latent variables.

[2] Wiebe et al. (2008) included the Shape School task in their CFA (similar to the Shape Game included in our study). However, they used latency as an a priori measure of inhibition.

The Role of Language in the Development of EF

The results from the present study are consistent with previous studies that have shown a significant relation between language and EF, and they extend previous research by demonstrating a significant and unique relation between syntactic ability and different components of EF.

Semantic Knowledge

The results from the hierarchical regression analyses show that semantic ability, or the understanding of the meaning of words, uniquely accounted for a significant proportion of the variance in the flexibility factor, but not in the WM/INH factor. Although semantic knowledge was not uniquely associated with WM/INH in the hierarchical regression analysis, the age-partialled correlation between semantic understanding and WM/INH is actually very similar to that age-partialled correlation between syntactic ability and WM/INH (part = .40 and part = .44, respectively). This suggests that semantic ability is not unrelated to WM/INH; rather, a large proportion of variance is shared with age ($r = .60$).

These findings support previous studies that have found an association between verbal ability and EF (e.g., Hughes, 2008) and studies that have found a facilitative effect of verbal labels on task-switching performance (e.g., Doebel & Zelazo, 2013; Kirkham et al., 2003). "Better" semantic knowledge refers to understanding and using a greater number and more abstract words. In accordance with Luria's (1959) suggestion, as children come to understand the specific meanings of words such as "press" or "don't press" in his Go/No-Go experiment, they are better able to use these words to regulate their behaviour. The association between semantic ability and flexibility also supports the "bottom-up" approaches proposed by Kirkham et al. (2003) and Yerys & Munakata (2006) to understand the role of labels in facilitating switching behaviour. Specifically, understanding semantic categories such as colour or shape can allow labels based on perceptual cues to bias or shift one's attentional to the relevant dimension.

Syntactic Ability

Consistent with our hypothesis, syntactic ability was found to uniquely account for a significant proportion of variance in both the flexibility and WM/INH factors. In contrast to the semantic aspect of language, which refers to the meanings of words, the syntactic aspect of language involves understanding the relation between words. Although the relation between general "language ability" (typically assessed using measures of semantic ability) and EF is well established in the literature, the results from the present study suggest that the structural aspect of language may be particularly important. This suggestion is supported by the results from our hierarchical regression, which found that structural complexity was uniquely associated with rule complexity or "post switch" performance in flexibility tasks.

These findings also lend support to Zelazo et al.'s CCC-r theory, which suggests that language functions as a top-down influence on executive functioning by allowing for the formulation high-order relational representations. Children who are able to comprehend and use sentences that are more syntactically complex may use this structure to form hierarchically embedded representations of rules to organize and direct their behaviour. From a Vygotskian perspective, the relations between words used in speech may become internalized, in addition to the words themselves.

Syntax and Semantics: General Linguistic Ability

Although I think it is interesting to examine the unique roles of syntactic and semantic ability in the development of EF, it is important to consider how they may interact and jointly contribute to early cognitive development. In everyday functioning, syntax and semantics are inextricably linked and, as Werner & Kaplan (1963) have said, “words and sentences are necessarily correlative in their unfolding” (p.138). Indeed, in the assessments of syntax used in the present study, comprehension of the meaning of specific words in addition to the structure of the sentence is required for successful performance (e.g., to choose the correct picture when presented with the sentence “the shoe that is above the square is red” the child has to both understand the meaning of each word, and that the relation between the embedded and main clauses). Future research may examine the mechanisms by which these different aspects of language interact to promote the development of EF. For example, as suggested by Doebel & Zelazo (2013), top-down influences may interact with bottom-up processes to influence shifting behaviour. It is possible that the semantic aspects of language may relate more to bottom-up influences such as when labels for the perceptual features of stimuli promote or inhibit switching (see studies by Kirkham et al. [2003] and Yerys and Munakata [2006]). By contrast, the syntactic aspect of language may underlie the manner in which language exerts a top-down influence on EF by facilitating the development of more complex and hierarchically embedded relations.

Limitations and Suggestions for Future Research

An important limitation of the present study is the small sample size, and the potential effect this has on the interpretation of our CFA results discussed above. Although the purpose of the CFA was not to examine the latent structure of EF per se, our results echo the discussion by Miller et al. (2012) and the impact that performance indicators can have on CFA results. Future studies utilizing a larger battery of EF tasks may help clarify the factor structure of EF in preschoolers, although some question the utility of CFA and latent variable approaches in understanding the structure of EF (Blair & Willoughby, in press).

Due to the small sample size in our study, we were also unable to employ structural equation modeling to test the unique relations between syntax, semantics, age, and different aspects of EF. Thus, we were unable to quantify and compare the individual contributions of syntax and semantics, as well as the contribution of “language ability” (both syntax and semantics).

Another potential limitation of the present study was the dependency of task instruction on language. Although the WM/INH and flexibility factors derived from CFA are theoretically more “pure” measures of EF reflecting the shared variance in the manifest variables, performance on all measures was dependent on the comprehension of verbally presented instructions. Disentangling language from EF tasks may yield more precise insights regarding the relation between the two.

The present study used a cross-sectional design, which limits the inferences that can be drawn with regards to directionality and causality. Although we propose that understanding and internalizing the complex structure of language facilitates flexible shifting behaviour, it may be the case that a certain degree of working memory capacity is necessary to learn or recognize the regularities in language (e.g., Gathercole & Baddeley, 1993). Future studies that employ a longitudinal, microgenetic, or training design would be informative in determining whether there are causal links between the different aspects of language and EF.

One recent study by Espinet, Anderson, and Zelazo (2013) found no effect of relative clause training on performance on the DCCS. Although this suggests that training syntax may not improve shifting or flexibility, it may be the case that the ‘dosage’ of training was relatively low (children observed 4 or 8 scenes and were asked a question that emphasized the use of a relative clause, e.g., “Did the baby doll hug the girl doll *who was* jumping up and down, or did the baby doll hug the girl doll *who was* sitting down?") or that flexibility may be related to the comprehension of other complex syntactic structures (e.g., hierarchically embedded or centre-embedded clauses). Future studies that measure a wider range of syntactic forms may help to clarify the specific relation between the syntax and EF.

General Conclusion

The aim of the present study was to systematically evaluate the association between different aspects of language, namely syntax and semantics, and different components of EF using a latent variable approach. The results showed that syntactic ability was uniquely associated with working memory/inhibition and flexibility, and that syntactic complexity was uniquely associated with rule-complexity in measures of flexibility. These findings support Zelazo et al.'s suggestion that flexible, self-regulatory behaviour develops as children are able to form more complex, hierarchically embedded rule structures. Furthermore, the association between syntactic ability and EF provides preliminary evidence that the structure of language, in addition to knowledge of words themselves, play an important role in the development of EF.

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Appendix

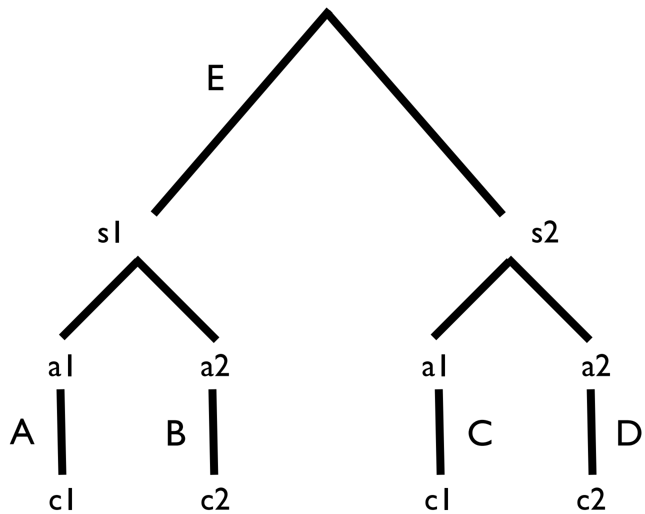

Figure 1 Hierarchical tree structure depicting formal relations among rules (adapted form Zelazo & Palfai, 1995)

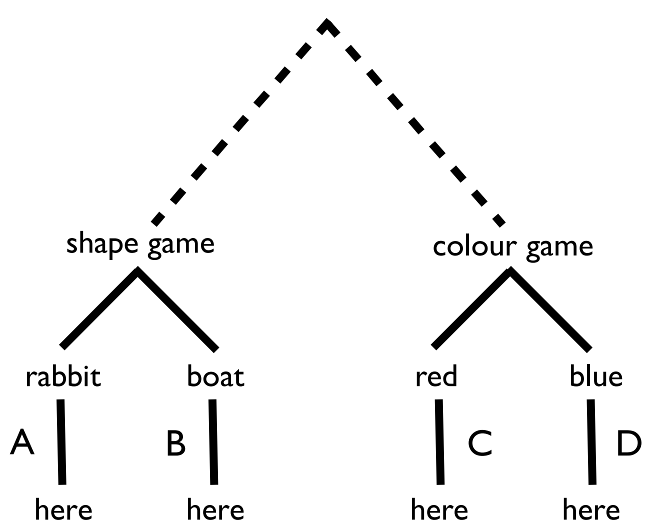

Figure 2. Unintegrated rule systems, in the absence of a higher order rule in the DCCS (adapted from Müller et al., 2009)

Table 1. Descriptive Statistics for Executive Function and Language Measures, and Age

Variable	*n*	*M*	*SD*	Range	Skew. (*SE*)	Kurt. (*SE*)
ECT total correct	66	5.17	7.25	1 – 10	-0.09 (.30)	-0.56 (.58)
WOT total correct	66	7.86	1.95	2 – 10	-0.69 (.30)	-0.54 (.58)
IPSyn total score	67	88.61	12.12	46 – 104	-1.51 (.29)	2.42 (.58)
CELF – Word Structure	67	18.09	3.73	5 – 24	-0.96 (.29)	1.25 (.58)
CELF – Expressive Language	67	25.85	6.72	10 – 38	-0.59 (.29)	-0.33 (.58)
CELF – Recalling Sentences	66	21.51	9.51	1 – 37	-0.39 (.30)	-0.79 (.58)
PPVT-4 highest set	58	9.83	2.27	4 – 13	-0.57 (.31)	-0.67 (.62)
EFSP highest level	67	4.06	1.03	2 – 7	0.13 (.29)	1.23 (.58)
FIST Selection 2 total correct	67	6.24	1.92	2 – 9	-0.05 (.29)	-0.98 (.58)
Shape Game efficiency score	64	0.25	0.12	0.00 – 0.61	0.25 (.30)	0.27 (.59)
Backward Word Span highest span	67	1.28	1.39	0 – 4	0.38 (.29)	-1.45 (.58)
Backward Digit Span highest span	66	1.58	1.27	0 – 3	-0.27 (.30)	-1.28 (.58)
Self-Ordered Pointing highest span	67	4.57	1.67	2 – 8	0.56 (.29)	-0.66 (.58)
Tapping Test total correct	66	9.46	5.42	0 – 16	-0.55 (.30)	-1.24 (.58)
HTKS part 1 total correct	67	10.28	7.8	0 – 20	-0.15 (.29)	-1.69 (.58)
GNG block 1 commission errors	57	1.82	2.16	0 – 10	2.12 (.32)	4.40 (.62)

Note. ECT = Embedded Clause Test; WOT = Word Order Test; IPSyn = Index of Productive Syntax; CELF = Clinical Evaluation of Language Fundamentals; PPVT-4 = Peabody Picture Vocabulary Test 4th Edition; HTKS = Heads-Toes-Knees-Shoulders task; GNG = Go/No-Go task.

Table 2. Zero-Order Correlations among Executive Function and Language Measures, and Age (*N*=67)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ECT	-															
2. WOT	.44**	-														
3. IPSyn	.43**	.38**	-													
4. CELF – WS	.29*	.52**	.58**	-												
5. CELF – EV	.24	.45**	.45**	.61**	-											
6. CELF – RS	.50**	.61**	.57**	.68**	.67**	-										
7. PPVT-4	.27*	.41**	.45**	.36**	.48**	.50**	-									
8. EFSP	.27*	.41**	.26*	.40**	.49**	.48**	.46**	-								
9. FIST	.16	.22	.26*	.26*	.31*	.26*	.42**	.39**	-							
10. SG	.30*	.31*	.32*	.29*	.46**	.39**	.21	.35**	.46**	-						
11. BWS	.23	.30*	.31*	.39**	.34**	.36**	.50**	.45**	.37**	.27*	-					
12. BDS	.30*	.46**	.50**	.57**	.48**	.65**	.51**	.47**	.33**	.35**	.52**	-				
13. SOP	.18	.45**	.19	.33**	.23	.27*	.10	.24*	.07	.24*	.29*	.27*	-			
14. TT	.29*	.20	.32**	.30*	.44**	.40**	.37**	.39**	.30*	.40**	.60**	.60**	.16	-		
15. HTKS	.24*	.48**	.41**	.56**	.43**	.56**	.59**	.54**	.37**	.32**	.55*	.67**	.22	.58**	-	
16. GNG	.24	.27*	.23	.27*	.55**	.41**	.37**	.27*	.22	.27*	.38**	.45**	.32**	.40**	.22	-
17. Age	.18	.32**	.33**	.37**	.61**	.49**	.36**	.51**	.34**	.47**	.43**	.64**	.11	.55**	.53**	.32**

Note. ECT = Embedded Clause Test; WOT = Word Order Test; IPSyn = Index of Productive Syntax; CELF = Clinical Evaluation of Language Fundamentals; WS = Word Structure subscale; EV = Expressive Vocabulary subscale; RS = Recalling Sentences subscale; PPVT-4 = Peabody Picture Vocabulary Test 4th Edition; EFSP = Executive Function Scale for Preschoolers; FIST = Flexible Item Selection Task Selection 2 total; SG = Shape Game efficiency score; BWS = Backward Word Span; BDS = Backward Digit Span; SOP = Self-Ordered Pointing; TT = Tapping Test; HTKS = Heads-Toes-Knees-Shoulders task; GNG = Go/No-Go task.

Table 3. Age-Partialled Correlations among Executive Function and Language Measures (*N* = 67)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. ECT	-														
2. WOT	.41**	-													
3. IPSyn	.40**	.30*	-												
4. CELF – WS	.25*	.46**	.52**	-											
5. CELF – EV	.16	.34**	.33**	.53**	-										
6. CELF – RS	.48**	.55**	.49**	.62**	.53**	-									
7. PPVT-4	.22	.34**	.38**	.26*	.36**	.39**	-								
8. EFSP	.21	.30*	.10	.27*	.26*	.30*	.35**	-							
9. FIST	.11	.13	.16	.15	.14	.11	.33**	.27*	-						
10. SG	.24*	.19	.20	.14	.25*	.21	.05	.15	.36**	-					
11. BWS	.17	.20	.19	.28*	.12	.19	.41**	.31*	.26*	.09	-				
12. BDS	.24	.35**	.39**	.47**	.16	.50**	.39**	.23	.16	.08	.37**	-			
13. SOP	.16	.44**	.16	.32**	.21	.25*	.06	.22	.03	.22	.27*	.25*	-		
14. TT	.23	.03	.17	.13	.16	.17	.23	.16	.14	.20	.48**	.39**	.12	-	
15. HTKS	.18	.38**	.29*	.47**	.16	.40**	.51**	.36**	.23	.09	.43**	.50**	.19	.40**	-
16. GNG	.19	.18	.14	.18	.47**	.30*	.30*	.13	.13	.15	.29*	.28*	.30*	.29*	.07

Note. ECT = Embedded Clause Test; WOT = Word Order Test; IPSyn = Index of Productive Syntax; CELF = Clinical Evaluation of Language Fundamentals; WS = Word Structure subscale; EV = Expressive Vocabulary subscale; RS = Recalling Sentences subscale; PPVT-4 = Peabody Picture Vocabulary Test 4th Edition; EFSP = Executive Function Scale for Preschoolers; FIST = Flexible Item Selection Task Selection 2 total; SG = Shape Game efficiency score; BWS = Backward Word Span; BDS = Backward Digit Span; SOP = Self-Ordered Pointing; TT = Tapping Test; HTKS = Heads-Toes-Knees-Shoulders task; GNG = Go/No-Go task.

Figure 3. Models of latent EF factor structure to be estimated and compared using confirmatory factor analysis. EFSP = Executive Function Scale for Preschoolers; FIST = Flexible Item Selection Task; HTKS = Heads-Toes-Knees-Shoulders

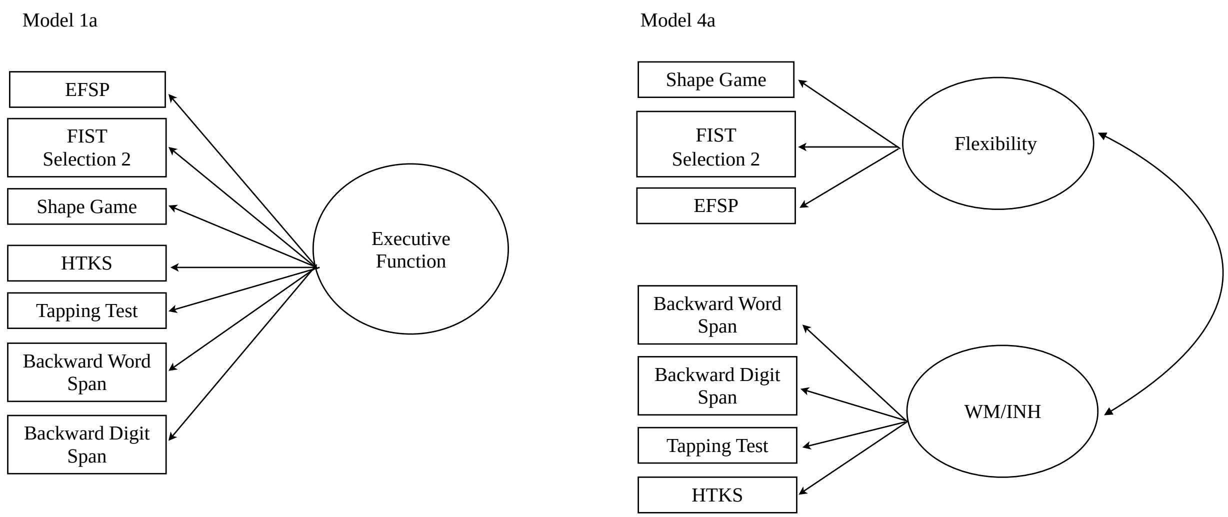

Figure 4. Post-hoc models of latent EF factor structure to be estimated and compared using confirmatory factor analysis. EFSP = Executive Function Scale for Preschoolers; FIST = Flexible Item Selection Task; HTKS = Heads-Toes-Knees-Shoulders

Table 4. Model Fit Indices for Confirmatory Factor Analysis Models (N = 67)

Model (number of factors)	*df*	$\chi^{2\,a}$	χ^2/df^{b}	CFI[c]	RMSEA[d]	AIC[e]	Model comparison	Δdf	$\Delta\chi^{2\,f}$
1. Unitary executive function (1)	27	21.98	1.22	.97	.058	68.99	Model 1 vs. *Model 4*	1	5.45*
4. WM/INH and Flexibility (2)	26	27.43	1.05	.99	.029	65.43			
Modified models (post-hoc)									
1a. Unitary executive function (1)	14	17.20	1.23	.98	.059	45.20	Model 1a vs. *Model 4a*	1	5.69*
4a. WM/INH and Flexibility (2)	13	11.51	.89	1.00	.000	41.51			

Note.
[a]Lower values indicated better model fit; values with $p \leq .05$ indicated that the model did not fit the data better than a saturated model.
[b]Values ≤ 3 indicated good model fit.
[c]Values $\geq .95$ indicated good model fit; values $\geq .90$ indicated adequate model fit.
[d]Values $\leq .06$ indicated good model fit; values $\leq .08$ indicated adequate model fit.
[e]When comparing models, lower values indicated the better model fit.
[f]Values with $p \leq .05$ indicated that the simpler model was significantly less satisfactory than the comparatively complex model.
* $p \leq .05$.

Table 5. Summary of Results for the Best Fitting Model 4a (*N* = 67)

Manifest variable	Latent factor	*B*	*SE*	Critical ratio	ß	R^2
Shape Game	Flexibility	1.00	-	-	.58	.33
FIST	Flexibility	1.13***	0.32	3.59	.64	.41
EFSP	Flexibility	1.25***	0.33	3.77	.70	.49
Backward Word Span	WM/INH	1.00	-	-	.71	.50
Backward Digit Span	WM/INH	1.11***	0.19	5.72	.79	.62
Tapping Test	WM/INH	1.05***	0.19	5.45	.75	.56
HTKS	WM/INH	1.14***	0.20	5.81	.81	.65

Note. FIST = Flexible Item Selection Task; HTKS = Heads-Toes-Knees-Shoulders; EFSP = Executive Function Scale for Preschoolers

*** $p \leq .001$.

Table 6. Zero-Order Correlations among Executive Function Factor Scores, Language Measures, and Syntax and Semantics Aggregate Scores (*N* = 67)

Measure	WM/INH	Flexibility
Age	.67**	.68**
ECT	.32**	.34**
WOT	.47**	.47**
IPSyn	.39**	.36**
CELF-WS	.57**	.53**
CELF-EV	.54**	.58**
CELF-RS	.63**	.60**
PPVT-4	.62**	.59**
Syntax Score	.58**	.57**
Semantics Score	.65**	.67**

Note. ECT = Embedded Clause Test; WOT = Word Order Test; IPSyn = Index of Productive Syntax; CELF-WS = Word Structure; CELF-EV = Expressive Vocabulary; CELF-RS = Recalling Sentences; PPVT-4 = Peabody Picture Vocabulary Test 4th Edition.
* $p < .05$. ** $p < .01$.

Table 7. Age-Partialled Correlations among Executive Function Factor Scores, Language Measures, and Syntax and Semantics Aggregate Scores (*N* = 67)

Measure	WM/INH	Flexibility
ECT	.29*	.32*
WOT	.36**	.37**
IPSyn	.33**	.30*
CELF-WS	.48**	.43**
CELF-EV	.23	.30*
CELF-RS	.44**	.39**
PPVT-4	.54**	.50**
Syntax Score	.50**	.48**
Semantics Score	.40**	.44**

Note. ECT = Embedded Clause Test; WOT = Word Order Test; IPSyn = Index of Productive Syntax; CELF-WS = Word Structure; CELF-EV = Expressive Vocabulary; CELF-RS = Recalling Sentences; PPVT-4 = Peabody Picture Vocabulary Test 4th Edition.
* $p < .05$. ** $p < .01$.

Table 8. Hierarchical Regression Analysis Predicting WM/INH from Syntactic and Semantic Ability

Step variable	*β*	Part	ΔR^2	ΔF	*df*
Step 1			.46	53.36**	1, 64
Age	.67	.67**			
Step 2			.15	11.78**	2, 62
Syntax	.32	.25**			
Semantics	.17	.11			
Model Test			.59	31.63**	3, 65

Note. *p ≤ .05; **p < .01

Table 9. Hierarchical Regression Analysis Predicting Flexibility from Syntactic and Semantic Ability

Step variable	*β*	Part	ΔR^2	ΔF	*df*
Step 1			.46	54.50**	1, 64
Age	.68	.68*			
Step 2			.15	12.70**	2, 62
Syntax	.27	.21**			
Semantics	.24	.16*			
Model Test			.59	32.42**	3, 65

Note. *p ≤ .05; **p < .01

Table 10. Zero-Order Correlations among Aggregate Scores of "Simple" Rule Use, "Complex" Rule Use, Syntactic Complexity, and Age (*N* = 63)

Measure	1	2	3	4
1. Age	-			
2. “Simple” rule use	.52**	-		
3. “Complex” rule use	.59**	.68**	-	
4. Syntactic complexity	.31*	.35**	.43**	-

Note. *p < .05; **p < .01