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Maureen Hoskyn

Institute for Research on Early Child Health and Education. Simon Fraser University, mhoskyn@sfu.ca

Irina Tzoneva

Institute for Research on Early Child Health and Education. Simon Fraser University

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Cover Page Footnote

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Irina Tzoneva

*Institute for Research on Early Child Health and Education
Simon Fraser University*

Abstract

The authors examined the nature of the working memory system that underlies age differences of young, preschool-aged children. Measures of working memory, short-term memory, articulation speed, general intelligence, and writing were administered to 166 Canadian preschool-aged children aged 3 to 5 years. Findings generally support the hypothesis that age-related differences in working memory capacity are a function of growth in a general executive as well as processing at lower levels. The results also showed that working memory predicted unique variance in name writing of preschoolers; however, this association was mediated by children's age (experience) and letter-copying skill.

Working memory is generally conceived as a multicomponent system that temporarily stores and manipulates information in the face of distraction and/or attention shifts (Baddeley & Logie, 1999; Just & Carpenter, 1992; Turner & Engle, 1989). The ability to selectively attend to information that is

important, while simultaneously inhibiting interfering information, is thought to mediate a wide range of cognitive and language activities that require reasoning, planning, and action in children (Savage, Cornish, Manly, & Hollis, 2006) and adults (Engle, 2002; Just & Carpenter, 1992; Turner & Engle, 1989). A number of studies have documented the developmental growth in working memory capacity that occurs over late childhood and adolescence (Gathercole et al., 2005; Hoskyn, 2004; Kail, 1997; Kail & Park, 1994; Swanson, 1999) and the age-related capacity declines that occur in later life (Hoskyn & Swanson, 2003; Swanson, 1999). Further, research shows that the expression of disabilities associated with learning (Gathercole & Alloway, 2006; Swanson & Ashbaker, 2000), language (Gathercole et al., 2005), and attention (Budson & Price, 2005) are associated with constraints in working memory capacity. Although a substantive body of knowledge about the relations between working memory and academic achievement in older children and adults exists, less is understood about the developing working memory system or its influence on children's early learning.

One problem faced by researchers interested in learning about working memory early in the human lifespan is that a widely accepted definition of the construct does not exist. A lack of conceptual clarity is present for a number of reasons. First, working memory is but one of several memory processes that develop in early childhood and distinguishing working memory as separate from other memory systems is historically controversial (Brown & Hulme, 1992; Cantor, Engle, & Hamilton, 1992; Conway et al., 2005). Second, working memory is not an isolated cognitive skill. Rather, it operates in tandem with other developing executive processes and cognitive skills that support children's early learning (Rothbart, Posner, & Kieras, 2006). Third, although working memory tasks are thought to be universal and performance differences rest within the constitution of the individual, it is possible that, like other developmental tasks, measures of working memory can be solved differently in different social and cultural environments (Greenfield, Keller, Fuligni, & Maynard, 2002). Despite these challenges, there is general consensus that the construct has scientific utility to research on human cognition and there is considerable interest in furthering understandings about the relations between a developing working memory system and early learning. To this end, the purpose of the present study is twofold: it is of interest to investigate (a) the nature of the working memory system that underlies age variation among young children; and (b) the relations between individual differences in working memory capacity and children's early learning and use of the alphabetic code in writing activities.

The Nature of the Developing Working Memory System

With respect to the first objective, it is generally accepted that as children grow older, overall working memory capacity increases. However, the primary question to be addressed in this study is whether age-related change in a general executive or in processing of domain-specific, lower level information within working memory accounts for this growth in overall capacity. Baddeley's model of working memory (1986, 1998, 2000) is well suited to this line of inquiry for it explains how a general executive operates in tandem with lower level processes within the working memory system. In this tripartite model, the domain-general central executive interacts with and allocates resources to two domain-specific, auxiliary slave systems: the visual-spatial sketchpad and the phonological loop. The visual sketchpad is responsible for the storage of visual-spatial information for a limited duration that in turn, supports the generation and manipulation of mental images. The phonological loop is utilized for the retrieval and temporary storage of phonological codes from long-term memory and is thought to be heavily involved in children's early acquisition of language (Baddeley, 2000). Processing in the phonological loop is assumed to be captured by measures of articulation speed on tasks where children are required to name a series of objects repeatedly and as quickly as possible. To perform such tasks, children search in long-term memory for phonological codes that are encoded, transformed, and retrieved to name each object. When the phonological representations stored in long-term memory are unstable, processing in the phonological loop is inefficient and slow, and the products relayed forward to the central executive are only partially formed. These partial-products are subsequently fed back from the executive to the phonological loop for further processing. As children mature and acquire language, phonological representations stored in long-term memory become more stable, and the rate at which phonological codes are accurately retrieved and temporarily stored within the phonological loop also increases. This faster rate of processing reduces the need for attentional resources from the executive and these resources can be allocated to other cognitive activities. Thus, age-related capacity increases are theoretically attributed to improvements in children's ability to process phonological information at lower levels within the working memory system.

An alternative hypothesis holds that change at the level of the central executive, irrespective of the efficiency of processing at lower levels in the phonological loop, account for developmental variation in working memory capacity. In this view, an expanding working memory executive *in combination* with improvements in processing efficiency account for age-related change. From this perspective, a working memory executive is responsible for attending to and allocating resources to the phonological loop, and as children

mature, they have greater resources available at the executive level to support processing at lower levels. In the present study, evidence to support the hypothesis that a working memory general executive, together with processing efficiency, contributes to children's early development is found if correlations between measures of age, working memory, and articulation speed are statistically significant *and* if working memory explains unique variance in age beyond that attributed to processing in the phonological loop (i.e., articulation speed; auditory short term memory).

A related question concerns whether the working memory system that underlies age-related change functions independently of a short-term memory system. A number of theorists propose that processing within the phonological loop and the visual-spatial sketchpad is synonymous with short-term memory; a passive, temporary storage buffer, the capacity of which is measured by simple memory span tasks and mediated by efficiency of practiced skills, such as rehearsal and chunking (Brown & Hulme, 1992). Alternatively, other theorists argue that a working memory executive that includes both a storage as well as an attention component (Conway, Cowan, Bunting, Theriault, & Minkoff, 2002) operates at least in part, independently of short-term memory (Cantor et al., 1992; Conway et al., 2005; Swanson & Ashbaker, 2000). Whether a task involves working memory is determined by the extent to which the maintenance of activation to memory representations is required to prevent its loss from the focus of attention due to interference or decay (Conway et al., 2002). Both viewpoints suggest that correlations between age, working memory, and short-term memory will be statistically significant; however, evidence to support the hypothesis that developmental differences in working memory capacity are distinct from those associated with short-term memory is found if working memory contributes unique variance to the prediction of age, beyond that attributable to short-term memory.

Working Memory and Early Writing

A second objective of this study is to investigate whether individual differences in working memory capacity contributes to young children's ability to perform on early writing tasks. Although skilled writing is a complex, multicursive activity that involves a number of language and cognitive processes (i.e., idea generation, spelling, use of vocabulary and/or syntax), among very young children and for the purposes of this study, the definition of writing is constrained to children's ability to print letters legibly in isolation (i.e., to create letters from memory) and to assemble letters to make a known word (i.e., personal name writing). During the preschool years, children learn that the words they hear about them can be represented by printed symbols known as

letters. One of the first writing acts they are likely to perform to communicate meaningfully with others using letters is printing their name. Theoretically, printing one's name requires the retrieval of specific orthographic representations from long-term memory into working memory, where this information is translated and used to support transcription of letters into printed form. Early on, the products of this processing may be scribbles that are not interpretable to anyone but the child; however, with practice, the scribbles morph into legible letters. Printing a name with letters that are legible to others demands attention as well as controlled processing and represents a cognitively demanding activity for children who are in the early phases of learning an alphabetic orthography. What is at issue in this present study is not whether variation in writing performance for young child-writers is related to higher level executive or lower level phonological/visual-spatial processes (see Berninger, 1999; Berninger, Abbott, Abbott, Graham & Richards, 2002; Berninger, Abbot, Thomson, & Raskind, 2001; Graham & Harris, 2000, for extensive reviews), but whether a working memory executive resource explains early writing over and above the well-defined, independent effects of processing at lower levels in the phonological loop or visual-spatial sketchpad.

A related issue concerns whether young children who are poor emergent writers can be differentiated from good writers on the basis of limitations in working memory capacity (i.e., they have relatively few executive resources available). One possibility is that working memory prepares young children to become good writers and therefore constraints in working memory capacity serve to slow development of writing skills. In this case, early constraints in working memory capacity may be a good candidate for studies interested in the prediction of writing disabilities in school-aged children. Alternatively, children's early literacy experiences may be more important to the development of early writing skills than their working memory capacity and therefore, working memory, at least in the early years, is not expected to be predictive of later writing difficulties.

To address these issues in the current study, multiple measures of working memory, short term memory, articulation speed, general intelligence, and writing are administered to 166 children who attend preschools and who range in age from 37 to 60 months. First, confirmatory factor analyses are conducted to verify the relations between the latent constructs that underlie the measures of working memory, short-term memory, and articulation speed. A series of hierarchical regression analyses are then conducted to investigate the factors that mediate relations between age-related change and working memory. Our hypothesis, as discussed earlier, is that the latent variable derived from the working memory measures will be highly predictive of age-related differences

in young children beyond that explained by articulation speed and short-term memory. Further, it is posited that individual differences in working memory capacity among this sample of preschoolers will predict early writing performance beyond the contribution of general reasoning ability (IQ), orthographic awareness, letter copying ability, short-term memory, and articulation speed. In short, this study examines the role of a working memory executive on children's early development and on their emerging literacy skills.

Method

Participants

One hundred and sixty-six children (mean age = 52 months, $SD = 7.51$ months, range 37 to 60 months) were selected from participating preschools in the lower mainland of British Columbia for study participation. Composite characteristics of the total sample are as follows: (a) gender: 44% female and 56% male; and (b) ethnicity: 53% Anglo, 19% Asian, 24% mixed heritage, 2% African-Canadian, 2% First Nations. All children in the study are Canadian-born and speak English at home. Socioeconomic status as estimated from Statscan data for this region of Canada ranges from lower to upper class. Parental education ranges from 11-21 years. No more than five children in the sample attend the same preschool, therefore, a wide range of approaches to fostering early childhood development through early literacy practices are represented. Each preschool is staffed by trained early childhood educators with whom children interact in a ratio of six to eight children to one early childhood educator. Among the preschools that reportedly adhere to a specialized approach, such as Montessori or Reggio Emilia, there is considerable variation in program delivery, with some preschools having more structured and adult-directed interactions with children than others. However, all early childhood educators in the sample report that play is an important component of their program and that children self-select activities for the majority of the preschool day. In all preschools, children are individually taught to print their names; however, instructional procedures are not formalized.

Procedures and Measures

All tests were administered individually to participating children over two 45-minute sessions on separate days. The testing took place either at the preschool that the child attended or in the child's home and was administered by a graduate level research assistant. Several short breaks were taken dur-

ing the testing to insure that children were actively engaged in the activities presented.

Working Memory

Four working memory measures — two verbal and two visual-spatial — were created by the first author to assess children’s working memory capacity from the age of 3 to 8 years. These tasks are based on a set of measures initially developed by H. Lee Swanson (Swanson Cognitive Processing Test, 1996) and were adapted for use with young children. All four subtests require the child to respond to both processing and storage questions. The processing of information is assessed by asking children a question about to-be-remembered material, whereas storage is assessed by accuracy of item retrieval. Each subtest generates three scores: (1) an initial score reflects the highest score obtained without external guidance from the research assistant, (2) a gain score or asymptotic level is the highest score obtained by the child with prompts, and (3) a maintenance score is obtained by re-administering the most difficult item on each subtest that the child was able to respond to accurately with prompts after all four subtests are administered with prompting procedures. During the maintenance condition, the child is not given prompts. A detailed description of each working memory task and prompting and scoring procedures follows¹:

Story Retelling. This task requires each child participant to retell a short story initially told by a research assistant with the assistance of a puppet named “Spotty.” The story details a sequence of events that occur at Spotty’s birthday party. At the conclusion of the story, a process question about one of the events at the party is asked and then the child is asked to retell the story with the puppet. The story consists of seven sentences ranging from 4 to 12 words in length. All sentences have a simple noun phrase/verb phrase structure with no complex clauses. There are 12 distinct propositions in the story such as: it is Spotty’s birthday, s/he (the puppet is gender matched to the child) is going to have a party, s/he’s turning a certain age (the same age as the child).

After the first administration of the task, each child is told that the story was very good, but that a few important details were left out. The child is informed about the details that s/he omitted and is asked to retell the story again without missing any parts of the story. The task is scored before and

1 Copies of the materials used for these working memory tasks are available from the first author upon request.

after prompting and at maintenance by awarding points for each proposition remembered (score range = 0 to 12). For the recall of a proposition to receive a point, it must be positioned accurately in relation to the other propositions recalled in the story. Internal consistency for initial, gain, and maintenance scores (Cronbach's alpha) is .85, .84, and .84 respectively.

Rhyming Words. This task requires each child to recall a set of spoken words that rhyme (e.g., "lip-slip-clip"). Each successive word in the set is presented to the child after a 2-second interval. Before recalling the words, the child is asked whether a particular word was included in the set. For instance, after being presented with the words "lip-slip-clip," the child is asked if "ship" or "lip" was included in the word set. The child is then requested to recall the spoken words (lip-slip-clip) in order. Administration of the task is stopped when the process question is failed or when the child incorrectly recalls two sets of words in a sequence.

On each item where the child omits a word, or incorrectly states the order of the words, the research assistant informs the child of the words missed in the set and asks the child to repeat the set of words again in order. The task is scored by assigning a point for each set of words recalled correctly in sequence. As on the Story Retelling task, three scores are calculated: before (initial), after prompting (gain), and at maintenance. If the child accurately recalls the single set of words administered at maintenance (i.e., the last set that was recalled accurately in the gain condition), the gain score is assigned. If the child makes an error on this item, either by omitting a word or by saying the words in the incorrect sequence, the initial score is assigned. The maintenance score is assumed to reflect the child's inability to maintain the memory trace in active working memory over time. Internal consistency (Cronbach's alpha) for initial, gain, and maintenance scores is .86, .85, and .86, respectively.

Visual Matrix. This task requires each child to copy a routine where a research assistant takes a pencil and taps a series of bright red plastic chips arranged on a matrix of squares on a large sheet of white paper. At the end of each routine, a process question is asked about whether the research assistant tapped a specific chip and then the child is given the pencil and asked to tap the same chips s/he saw the research assistant tap in temporal order. As items increase in difficulty, the size of the matrix increases. If the child fails the process question, the task is stopped. The task continues until the child performs incorrectly on two items in the sequence.

On each item where the child omits or taps additional chips, or when the chips are tapped in the incorrect order, the research assistant informs the child

that certain chips were missed and the child is asked to perform the item again by tapping the correct chips in the correct order. The task is scored by assigning a point for each routine accurately reproduced by the child. Initial, gain, and maintenance scores are calculated in the same manner as on the Rhyming Words subtest. Initial and gain scores are the total number of routines accurately performed before (initial) and after (gain) prompting. The maintenance score is calculated as follows: if the child accurately taps the sequence of chips on the item administered at maintenance (i.e., the highest item correctly performed in the gain condition), the gain score is assigned; if the child makes a mistake on this item, the initial score is assigned. Internal consistency (Cronbach's alpha) is .85 for each condition (initial, gain, and maintenance scores).

Spatial Organization. This task requires the child to memorize an array of objects that have been placed on circles on a white sheet of paper and replace the objects in the correct spots on an array of blank circles. The research assistant administers the task by first taking a number of small objects (i.e., toy ring, eraser, sticker) out of a bag and placing them slightly out of reach of the child. A sheet of paper with large circles arranged separately on the page is placed in front of the child. The child is then told to look away while the research assistant arranges the objects on the paper. The child is then asked to study the objects and remember where they have been placed on the paper. After 10 seconds, the research assistant removes the objects from the paper. A process question is asked, the objects are given to the child, (including one extra distractor object), and the child is requested to place the objects in their correct spot and to give back any objects that do not belong on the paper. The task is stopped if the child fails a process question on an item or when the child fails two items in sequence.

On each item where the child makes an error placing the objects, the child is informed where these objects should be placed on the array. All the objects are gathered and given to the child who is requested to place them in the correct spots on the array. The task is scored by assigning a point for each set of objects accurately placed in an array by the child. The number of sets accurately recreated prior to and after prompting are calculated to reflect initial and gain scores, respectively. If the child accurately places the objects on the array at maintenance, the gain score is assigned. If the child makes a mistake in placing the objects, the initial score is assigned. Internal consistency (Cronbach's alpha) is .85 for each measure (initial, gain, and maintenance scores).

Cognitive Ability/Short-Term Memory

General cognitive ability (IQ) is estimated from children's performance on a measure of verbal (Vocabulary) and visual reasoning (Pattern Analysis) of the *Stanford-Binet Intelligence Scale-IV Edition* (SB:FE; Thorndike, Hagen, & Sattler, 1986). Subtest reliabilities ranged from .73 to .94. The Vocabulary subtest requires children to provide definitions for spoken words; Pattern Analysis requires children to identify patterns of objects in an array and to recognize what components are required to complete the array. Raw scores on the Memory for Sentences and Bead Memory subtests were used as simple span measures of short-term memory. On the Memory for Sentences subtest, children are requested to repeat a spoken sentence. The Bead Memory subtest requires children to memorize a series of beads that differ on the dimensions of colour and shape and that are shown to them either on a picture array or on a picture where the beads are stacked vertically in a column. Children are requested to select the correct beads from a box of beads and to arrange them in the same order observed in the picture.

Articulation Speed

An adaptation of a task and procedures reported in Swanson and Ashbaker (2000), and first developed by McDougall, Hulme, Ellis, and Monk (1994), is used in the study to measure articulation speed. Children are presented with three sequential arrays of five pictures of words that vary in length. The first array is formed with single syllable words, the second array is composed of two syllable words, and the third array is formed with three syllable words. The child is requested to name the pictures in temporal order five times, as quickly as possible. Responses to this task are digitally recorded and the time taken to name each list is calculated by SALT (Systematic Analysis of Language Transcripts) software to the nearest one-hundredth of a second. Internal consistency for Articulation speed of short, medium, and long words is .74, .76, and .79, respectively.

Orthographic Awareness

Orthographic awareness is assessed with a task developed by Berninger & Abbott (1994), during which children are first presented with a pseudoword for 5 seconds; the word is then covered, a letter is shown to the child, and the child is asked whether or not the letter was a part of the word that s/he recently viewed. Children receive one point for accurately recognizing whether the let-

ter is or is not a component of the word that they have viewed. Internal consistency (Cronbach's alpha) for this measure is .79.

Early Writing

Children in the sample completed three writing tasks, all of which were scored for legibility. On the Name Writing task, the child is requested to print his/her name on a sheet of blank, white paper. On Letters from Memory task, the child is asked to identify a letter or group of letters on a card and then print the letter(s) from memory on a sheet of blank, white paper. On the Letter Copying task, the child is asked to copy single and groups of letters (up to three letters) on a sheet of blank, white paper. On each of the three tasks, a score of 0 indicates that the letter was illegible and can not be differentiated from simple shapes and squiggles; a score of 1 indicates that the letter is partially formed, but identifiable; and a score of 2 indicates that the letter is accurately formed and legible. The number of points earned for each letter formed is summed for a total score on each measure. Internal consistency (Cronbach's alpha) estimates are as follows: Name Writing (.81), Letters from Memory (.82), and Letter Copying (.68).

Results

The results are presented in four sections. First, descriptive statistics and zero-order correlations are presented. Second, a series of confirmatory factor analyses are presented to verify the correct measurement model associated with the working memory, short-term memory, and articulation speed measures. Third, findings from several hierarchical regression models are presented. The first set of models examines the relations between age and the three latent constructs of working memory, short-term memory, and articulation speed. The final model investigates the role of working memory on children's early writing performance. Fourth, to further investigate whether differences in working memory capacity can be found among good and poor emergent writers, an analysis of variance with age as a covariate and working memory as the criterion was performed on subgroups of writers within the sample. For all significance tests, alpha is set at .05. For the confirmatory factor analyses, the fit of each model is evaluated using chi-square, goodness-of-fit (GFI), adjusted goodness-of-fit (AGFI), Akaike's information criterion (AIC), the comparative fit index (CFI), and the root-mean-square error of approximation (RMSEA). All analyses are conducted using SAS statistical software.

As shown in Table 1, all measures meet standard criteria for univariate normality for the indices of skew (less than 3) and kurtosis (less than 4) on all measures. There are no univariate outliers, defined here as cases more than 3.5 standard deviations from the mean. The data is also examined for multicollinearity by examining first-order correlations among measures. Moderate intercorrelations (.70 to .75) are found among the initial, gain, and maintenance scores on the Story Retelling task; extremely high intercorrelations (above .80) are found among these scores on the Rhyming Words, Visual Matrix, and Spatial Organization tasks. The mean change in scores from the initial to the gain condition is statistically detectable on all four measures of working memory: Story Retelling ($t = 8.55, p < .001$); Rhyming Words ($t = 6.25, p < .001$); Visual Matrix ($t = 6.01, p < .001$); and Spatial Organization ($t = 10.63, p < .001$). The average change in scores from the gain to the maintenance condition is also statistically significant on all four measures of working memory: Story Retelling ($t = -5.60, p < .001$); Rhyming Words ($t = -4.25, p < .001$); Visual Matrix ($t = -5.09, p < .001$); and Spatial Organization ($t = -7.97, p < .001$). However, on average, scores in the maintenance condition are lower, relative to the gain condition, which suggests that the majority of children in the sample are unable to maintain a stable memory trace in working memory over an extended period of time. Taken together, these findings indicate that on average, children benefit from prompting procedures; however, this incremental change in scores is lost over time. Moreover, these relations appear to be relatively stable across individuals. To minimize the likelihood of multicollinearity, gain scores (i.e., asymptotic level of performance) on each working memory task are selected for inclusion in the final measurement model.

Zero-order correlations for all measures used in the analyses are reported in Table 2. Significant findings are as follows: First, intercorrelations between verbal and visual measures of working memory range from .32 to .42, which are slightly smaller in magnitude than reported in previous research with older samples of children and adults (e.g., Engle, Tuholski, Laughlin, & Conway, 1999). Second, significant ($p < .01$) intercorrelations are found among the articulation speed (.60 to .69) and short-term memory (.36) measures. To further investigate these relations, a confirmatory factor analysis is conducted with three latent variables: working memory, short-term memory, and articulation speed. There are no correlations greater than .80 among the variables that constitute these latent constructs; therefore, multicollinearity is not expected to be a factor that influences findings of the confirmatory factor analyses.

To evaluate whether working memory and short-term memory are best viewed as independent constructs, two models are constructed. In Model A, both working memory and short-term memory measures are specified to load

Table 1
Descriptive Statistics for Memory, Processing Speed, and Writing Measures

Measure		Mean	SD	Skew	Kurtosis
Story retelling	Initial	2.80	2.28	.81	.47
	Gain	4.28	2.60	-.01	-.80
	Maintenance	3.46	2.51	.37	-.51
Rhyming words	Initial	.46	.67	1.18	.13
	Gain	.70	.79	.83	-.23
	Maintenance	.58	.77	1.14	.54
Visual matrix	Initial	.94	1.00	.64	-.87
	Gain	1.24	1.17	.47	-.75
	Maintenance	1.02	1.09	.76	-.14
Spatial organization	Initial	.95	.87	.51	-.61
	Gain	1.46	1.19	.02	-1.43
	Maintenance	1.07	.96	.41	-.90
Digit span		13.31	4.34	-.15	.28
Bead memory		9.61	4.34	1.00	1.18
Articulatory speed –	short words	46.24	18.12	1.45	3.11
	medium words	55.64	22.56	1.58	3.29
	long words	63.73	26.93	1.35	2.86
Orthographic awareness		7.70	3.01	-.63	.48
Letters copied from memory		1.20	2.51	2.01	2.70
Letter copying		10.92	11.49	.49	-1.42
Name writing		.81	.81	.35	-1.41

Table 2
Zero-Order Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Story-retelling	-														
2. Rhyming words	.35	-													
3. Visual matrix	.34	.32	-												
4. Spatial organ.	.40	.41	.40	-											
5. STM-sentence	.22	.44	.27	.37	-										
6. STM-bead	.21	-.24	.28	.36	.36	-									
7. Artic speed-short	-.19	-.23	-.02	-.18	-.36	-.24	-								
8. Artic speed-med	-.15	-.18	-.04	-.21	-.44	-.20	.67	-							
9. Artic speed-long	-.17	-.20	-.06	-.08	-.27	-.14	.69	.60	-						
10. Orthographic	.16	.08	.07	.25	.18	.23	-.22	-.31	-.27	-					
11. Letter copying	.24	.27	.41	.32	.34	.39	-.33	-.26	-.29	.31	-				
12. Letters memory	.12	.11	.20	.17	.19	.22	-.28	-.23	-.24	.17	.69	-			
13. Name writing	.18	.29	.26	.30	.33	.37	-.27	-.21	-.21	.30	.69	.41	-		
14. Vocabulary	.27	.32	.24	.25	.47	.28	-.24	-.28	-.13	.13	.26	.10	.25	-	
15. Visual reasoning	.12	.18	.30	.32	.25	.41	-.12	-.18	-.09	.25	.30	.13	.20	.30	-
16. Age	.33	.48	.39	.44	.48	.41	-.42	-.36	-.36	.19	.57	.38	.57	.41	.38

Note. Correlations in bold are significant $p \leq .05$.

on one factor and a second factor is created with the articulation speed measures. In Model B, working memory and short-term memory measures are specified to load on separate factors and articulation speed measures are specified to load onto a third factor. Table 3 presents the fit statistics for these two models. All fit indices suggest that Model B is a better fit than Model A. Model B correlations between the latent construct of working memory and short-term memory (.77), working memory and articulation speed (-.35), and short-term memory and articulation speed (.66) indicate a moderate degree of association. Based on this analysis, working memory and short-term memory are specified as separate variables in the following hierarchical regression models.

Prior to conducting hierarchical regression analyses, raw scores on each measure are transformed into z-scores based on the average sample variance. Composite scores are created by adding together the z-scores obtained by a participant on each of the measures that formulate the latent construct: working memory (story-retelling, rhyming words, visual matrix, and spatial organization), short-term memory (bead memory and memory span), articulation speed (short, medium, and long words) and writing (name writing and letter copying). The first set of hierarchical regression analyses are conducted on the criterion measure of age, with working memory, short-term memory, and articulation speed as predictors. Zero-order correlations between age and working memory (.57, $p < .001$), short-term memory (.54, $p < .001$), and articulation speed (-.34, $p < .001$) are significant. As reported previously, findings from the confirmatory factor analyses show that intercorrelations among the latent predictors are also statistically detectable. Results of these regression models are reported in Table 4 and Table 5.

Models 1 and 2 evaluate the relations between working memory and short-term memory in the prediction of age. Articulation speed is entered first into both models to account for the variance in age due to the speed of encoding, transforming, and retrieval of information. In Model 1, short-term memory is entered prior to working memory. Results show that working memory accounts for an additional 10% of the variance in age beyond the 25% attributed to short-term memory. In Model 2, the order of entry of the two memory variables is reversed. Results show that short-term memory accounts for 8% of variance in age beyond that attributed to working memory. These findings suggest that working memory and short-term memory each contribute unique variance to the prediction of age differences among preschoolers.

In Models 3 and 4, variables associated with general intelligence (i.e., verbal and visual reasoning) are also considered as possible mediators of age-working memory relations. As shown in Model 3, addition of these two vari-

Table 3
Fit Statistics for Confirmatory Factor Analyses

	<i>df</i>	χ^2	<i>P</i>	GFI	AGFI	AIC	CFI	RMSEA
Model A	24	30.06	.02	.93	.87	-8.39	.94	.07
Model B	21	25.68	.22	.96	.91	-16.31	.98	.04

Note. Model A: Working memory and short-term memory measures are loaded on one factor; Model B: Working memory and short-term memory measures load on separate factors.

Table 4
Hierarchical Regression Analyses of Factors Associated with Age

Variable	Age	
	R ²	ΔR ²
Model 1		
1. Articulation speed	.11*	
2. STM	.34	.23*
3. Working memory	.44	.10*
Model 2		
1. Articulation speed	.11*	
2. Working memory	.36	.25*
3. STM	.44	.08*
Model 3		
1. Vocabulary	.15*	
2. Visual Reasoning	.24	.09*
3. Articulation speed	.29	.05*
4. STM	.39	.10*
5. Working memory	.47	.08*
Model 4		
1. Working memory	.31*	
2. STM	.42	.09*
3. Articulation speed	.44	.01
4. Vocabulary	.46	.02*
5. Visual reasoning	.47	.01

Note. * $p \leq .01$

Table 5
Hierarchical Regression Analyses of Factors Associated with Name Writing

Variable	Name Writing	
	R ²	ΔR ²
Model 5		
1. Age	.33*	
2. Orthographic awareness	.36	.03*
3. Letter copying	.69	.33*
4. Articulation speed	.69	.
5. STM	.69	-
6. Working memory	.70	.01*

Note. * $p \leq .01$

ables prior to articulation speed, short-term memory, and working memory reduces the amount of variance in age attributed to working memory from 10% to 8%. Notably, each variable in the model continues to account for statistically significant increases in the R² and together they account for 47% of the total variance in age. Taken together, these findings provide tentative evidence to suggest that a working memory executive contributes to the explanation of variation in age, independent of that accounted for by processing in the phonological loop and/or the visual-spatial sketchpad. Model 4 further evaluates the importance of the three variables associated with the working memory system (i.e., articulation speed, short-term memory, and working memory) relative to general cognitive variables in the prediction of age by reversing the order of entry of the variables. When the variables associated with working memory are entered into the model first, followed by verbal and then visual reasoning, the contribution of verbal reasoning is reduced (i.e., from 15% to 2%) and the variance in age attributed to visual reasoning is reduced to non-significant. This result provides tentative support for the idea that age-related change among preschoolers is predicted better by variance associated with a working memory system than by differences in general reasoning abilities. Further, the findings

suggest that working memory mediates relations between age and general reasoning; however, there is limited evidence to suggest that the reverse is true.

As shown in Table 5, Model 5 evaluates whether individual differences in working memory capacity explain unique variance in children's early writing performance. First, a composite measure of writing is created by summing standardized z-scores on the name writing and writing letters from memory tasks. These two tasks require that the child hold information about the letters temporarily in mind while simultaneously scribing these mental representations of letters into print. Model 5 tests the assumption that individual differences in children's age (writing experience), their knowledge of an alphabet orthography (i.e., orthographic awareness), and their ability to scribe letters (letter copying) are strong predictors of writing ability. In total, 69% of the variance in children's early writing was explained by these three variables together. The variance in writing accounted for by short-term memory and articulation speed beyond that shared with age, orthographic awareness, and letter copying was not statistically detectable. Working memory contributed an additional 1% of variance to the model, which, although statistically detectable ($p < .05$), may not hold much practical significance.

Finally, it was of interest to determine whether differences in working memory capacity among good and poor writers were statistically detectable for children in this age range. A good writer was defined here as a child who performed at or greater than 1.0 standard deviations from the sample mean on the writing composite measure; a poor writer was a child who performed below -1.0 standard deviations from the mean on the composite measure of writing. Results of an analysis of variance showed that on average, group differences in working memory capacity, after controlling for age, were not statistically detectable, $F(1, 88) = .12, p = .74$. For children at this very young age, individual differences in working memory capacity does not appear to differentiate children who are good writers from those who have few writing skills.

To summarize, the important findings from these analyses are as follows. First, taken together, the results of paired comparison *t*-tests and zero-order correlation analyses provide empirical support to affirm that scaffolding in the form of prompts, on average, improves children's performance on working memory tasks; however, most young children are not able to maintain an active memory trace of the contents of working memory over time. Second, findings from the confirmatory factor and hierarchical regression analyses show that age-related change is predicted by variance in working memory capacity, irrespective of articulation speed or short-term memory, variables that are associated with processing in the phonological loop and visual-spatial sketch-

pad. Finally, individual differences in this developing working memory system accounts for significant, albeit a somewhat small amount of unique variance in children's early writing performance. Moreover, on average, differences in working memory capacity between extreme groups of good and poor writers were not statistically detectable.

Discussion

The findings of this study provide evidentiary support for the hypothesis that age-related change among young children is attributable to capacity increases in a general executive as well as age-related improvements in processing associated with the phonological loop and the visual-spatial sketchpad. This general conclusion stands in contrast to a body of literature that suggests processing speed at lower levels in the working memory system account for age-related growth in working memory capacity in older children and adults (Kail, 1997); however, it is consistent with recent studies that report a general executive working memory system underlies both increases in working memory capacity among children in the elementary (Gathercole et al., 2005) and secondary school years (Hoskyn & Swanson, 2003; Swanson, 1999) and decreases in working memory capacity associated with the cognitive decline of elderly adults in their later years (Hoskyn & Swanson, 2003).

Also important is the finding from confirmatory factor analyses that among preschool-aged children, performance on short-term memory tasks differs from performance on working memory tasks. These results have implications for studies that link short-term memory to young children's early academic or social outcomes (e.g., McDougall et al., 1994) for they suggest that tasks used to measure short-term memory in previous studies may also be tapping into working memory to some degree.

The findings of the present study also lead to the speculation that age and individual variation in working memory among preschool-aged children is synonymous with capacity differences in controlled attention which is under the control of a general executive (Engle et al., 1999). That is, children who have larger working memory capacities, either due to age or individual variation, have sufficient capacity to keep a memory trace active in the face of distraction or concurrent processing. This explanation is consistent with the view that the function of the central executive in working memory is to maintain goal-relevant information and to inhibit the activation of goal-irrelevant information during processing (Hanauer & Brooks, 2005; Rennie, Bull, & Dia-

mond, 2004). Certainly, the distractor question that is included to discriminate working memory from short-term memory tasks in the present study may operate more to assess children's ability to ignore task-irrelevant information than to evaluate the functioning of a mature working memory executive system in which information is updated and transformed to meet constantly changing cognitive goals.

Another possible explanation for the age variation in working memory capacity is that performance on working memory tasks is influenced by children's use of strategies. Strategies that are more complex than chunking and rehearsal may be required on working memory tasks when interference is introduced (i.e., when a process question is asked). According to this perspective, access to domain-specific experiences where children acquire a sophisticated set of strategies to formulate knowledge representations increases processing efficiency and overall working memory capacity. In the present study, evidence to support this hypothesis would be found if the correlations between age and working memory scores after prompting (gain scores) were significantly reduced relative to the correlations obtained between age and working memory prior to prompting (initial scores). This reduction in the magnitude of the correlations is expected because age differences in processing efficiency are minimized when prompts are provided. On average, children in the sample benefited from cues to increase performance on working memory tasks; however, this improvement in processing efficiency failed to reduce the significance and/or the magnitude of the observed correlations between age and working memory. Further, intercorrelations between initial, gain, and maintenance scores on three of the four working memory measures were greater than .80, which suggests any increases in strategy use through repeated exposure to the task over the course of the study benefits older children (who theoretically have a greater repertoire of strategies) and younger children (who have fewer strategies to draw upon) equally.

Finally, it is important to clarify the relations observed between working memory and early writing in this study. Young children in the early stages of writing development likely find letter formation a cognitively challenging, recursive, multidimensional task. Young child writers who are able to legibly print more letters from memory may be those children who, at this early age, show ability to focus on the task at hand and on the experiences in their everyday lives that indirectly contribute to their implicit understandings of the alphabetic system (e.g., by watching a caregiver make a shopping list, attending to the print of a storybook that is read to them). Notably, experience (age) and letter copying ability accounted for 94% of the explained variance in children's early writing ability $[(33+33)/70 = 94]$. Working memory accounted for only

1% of the explained variance in writing beyond these variables, which suggests that children's access to literacy practices that foster orthographic awareness and the ability to scribe letters far outweighs the importance of working memory in the prediction of children's early writing during the preschool years. Notably, average group differences in working memory capacity between children identified as good and poor emergent writers were not statistically detectable. This finding suggests that at least in the short term, variability in children's early experiences may be more predictive of writing difficulties than differences in working memory capacity. Whether these relations remain stable over time is not clear from findings in this study; further research using longitudinal designs is required to clarify working memory-writing relations for young children who later struggle with writing during the school years.

In conclusion, the current project suggests that age-related change in working memory capacity is associated with growth in a general executive system as well as increases in processing efficiency. In the short term, preschooler's access to early literacy practices that facilitate their ability to copy and form legible letters is more important than working memory to the prediction of writing performance. However, the ways in which early development of a working memory executive system influences long-term social and academic outcomes for children remains to be determined and is an important topic for future research.

References

- Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon.
- Baddeley, A. D. (1998). *Human memory: Theory and practice*. Boston: Allyn & Bacon.
- Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417-422
- Baddeley, A. D., & Logie, R. H. (1999). The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28-61). Cambridge, UK: Cambridge University Press.
- Berninger, V. (1999). Coordinating transcription and text generation in WM during composing: Automatic and constructive processes. *Learning Disability Quarterly*, 22, 99-112.

- Berninger, V., & Abbot, R. D. (1994). Redefining learning disabilities: Moving beyond aptitude-achievement discrepancies to failure to respond to validated treatment protocols. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement* (pp. 163-183). Baltimore, MD: Paul H. Brookes.
- Berninger, V., Abbot, R., Abbott, S. P., Graham, S., & Richards, T. (2002). Writing and reading: Connections between language by hand and language by eye. *Journal of Learning Disabilities, 35*, 39-70.
- Berninger, V., Abbot, R., Thompson, J., & Raskind, W. (2001). Language phenotype for reading and writing disability: A family approach. *Scientific Studies in Reading, 5*, 59-105.
- Brown, G. D., & Hulme, C. (1992). Cognitive psychology and second language processing: The role of short term memory. In R. J. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 105-121). Oxford, England: North-Holland.
- Budson, A. E., & Price, B. H. (2005). Memory dysfunction. *The New England Journal of Medicine, 352*, 692-699.
- Cantor, J., Engle, R. W., & Hamilton, G. (1992). Short-term memory, working memory and verbal abilities: How do they relate? *Intelligence, 15*, 229-246.
- Conway, A. R. A., Cowan, N., Bunting, M. F., Theriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed and general fluid intelligence. *Intelligence, 20*, 163-183.
- Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*, 769-786.
- Engle, R. W. (2002). Working memory capacity as executive function. *Current Directions in Psychological Science, 11*, 19-23.
- Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short term memory, and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General, 128*, 309-331.
- Gathercole, S. E., & Alloway, T. P. (2006). Practitioner review: Short-term and working memory impairments in neurodevelopmental disorders: Diag-

- nosis and remedial support. *Journal of Child Psychology and Psychiatry*, 47, 4-15.
- Gathercole, S. E., Tiffany, C., Briscoe, J., Thorn, A., & ALSPAC team (2005). Developmental consequences of poor phonological short-term memory function in childhood: A longitudinal study. *Journal of Child Psychology and Psychiatry*, 46, 598-611.
- Graham, S., & Harris, K. (2000). The role of self-regulation and transcription skills in writing and writing development. *Educational Psychologist*, 35, 3-12.
- Greenfield, P.A., Keller, H., Fuligni, A., & Maynard, A. (2002). Cultural pathways through universal development. *Annual Review of Psychology*, 54, 461-490.
- Hanauer, J. B., & Brooks, P. J. (2005). Contributions of response set and semantic relatedness to cross-modal Stroop-like picture-word interference in children and adults. *Journal of Experimental Child Psychology*, 90, 21-47.
- Hoskyn, M. (2004) *Working memory and emergent writing: What develops?* Paper presented at the American Psychological Association Annual Conference, Honolulu, HI, June, 2003.
- Hoskyn, M., & Swanson, H. L. (2003). The relationship between working memory and writing in older and younger adults. *Reading and Writing: An Interdisciplinary Journal*, 16, 759-784.
- Just, M., & Carpenter, P. A. (1992). A capacity theory of comprehension differences in working memory. *Psychological Review*, 99, 122-149.
- Kail, R. (1997). Phonological skill and articulation time independently contribute to the development of memory span. *Journal of Experimental Child Psychology*, 67, 57-68.
- Kail, R., & Park, Y. (1994). Processing time, articulation time, and memory span. *Journal of Experimental Child Psychology*, 57, 281-291.
- McDougall, S., Hulme, C., Ellis, A., & Monk, A. (1994). Learning to read: The role of short-term memory and phonological skills. *Journal of Experimental Child Psychology*, 58, 112-133.
- Rennie, D., Bull, R., & Diamond, A. (2004). Executive functioning in pre-schoolers: Reducing the inhibitory demands of the Dimensional Change Card Sort Task. *Developmental Neuropsychology*, 26, 423-443.

- Rothbart, M. K., Posner, M. I., & Kieras, J. (2006). Temperament, attention and the development of self-regulation. In K. McCartney & D. Phillips (Eds.), *Handbook of early childhood development* (pp. 167-187). New York: Blackwell.
- Savage, R., Cornish, K., Manly, T., & Hollis, C. (2006). Cognitive processes in children's reading and attention: The role of working memory, divided attention and response inhibition. *British Journal of Psychology*, *97*, 365-385.
- Swanson, H. L. (1996). *The Swanson Cognitive Processing Test*, Austin, TX: Pro-Ed.
- Swanson, H. L. (1999). What develops in working memory? A lifespan perspective. *Developmental Psychology*, *35*, 986-1000.
- Swanson, H. L., & Ashbaker M. H. (2000). Working memory, short term memory, speech rate, word recognition, and reading comprehension in learning disabled readers: Does the executive system have a role? *Intelligence*, *28*, 1-30.
- Systematic Analysis of Language Transcripts Software. (2007). Muscodia, WI: SALT Software LLC.
- Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). *Stanford-Binet Intelligence Scales* (Fourth Edition). Rolling Meadows, IL: Riverside Publishing Co.
- Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127-154.

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