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The Language, Working Memory, and Other Cognitive Demands of Verbal Tasks

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Purpose: To gain a better understanding of the cognitive processes supporting verbal abilities, the underlying structure and interrelationships between common verbal measures were investigated. **Methods:** An epidemiological sample ($n = 374$) of school-aged children completed standardized tests of language, intelligence, and short-term and working memory, as well as nonstandardized measures of grammaticality judgment, rapid naming, and sentence recall. **Results:** Results of a principal component analysis revealed 4 factors corresponding to domain-general working memory, language processing, phonological short-term memory, and fluid reasoning. In corresponding analyses based on younger and older halves of the data, more variables loaded on the fluid reasoning factor for the younger group, and more task variance was explained by the language or phonological storage factors for the older group. The language processing factor correlated with all of the nonstandardized measures, whereas rapid naming was additionally correlated with working memory. **Discussion/conclusions:** Separable cognitive processes influence performance on common verbal measures, which has implications for assessment and intervention of children with developmental language impairments. **Key words:** *intelligence*, *short-term memory*, *specific language impairment*, *working memory*

VERBAL ABILITIES are measured in a variety of ways, such as by asking people to follow verbal directions, remember phonological information, and identify similarities between verbally presented items. The cognitive processes proposed to underlie these tasks are a matter of some debate. Some would argue that these verbal tasks tap a unitary language processing factor (MacDonald & Christiansen, 2002), whereas others have suggested that these measures place demands on various cognitive processes such as working memory (Alloway, Gathercole, Willis, & Adams, 2004) and crystallized knowledge (McGrew, 2005). This study aimed to contribute to understanding of the cognitive processes supporting verbal abilities by investigating the underlying structure and interrelationships among common verbal measures.

MEASURES OF LINGUISTIC ABILITY

One set of verbal tasks comes from those who are studying language and language disorders. The measures are aimed at assessing core language ability, including the rules for governing the content of language represented in the semantic or meaning-based

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system, and rules for governing the form of language, including the phonological system for representing language sounds and the morphosyntactic system for combining part words, words, and sentences. The rules pertaining to language use also may be targeted in some tasks. Traditional tests of core language abilities include measures of the ability to understand language known as receptive language and the ability to produce language known as expressive language. Receptive language measures include tasks such as following directions (e.g., "touch the third circle and the first black square") and choosing one of several pictures corresponding to a given word or sentence. Expressive language tasks include creating a sentence using a given word and completing a sentence using a word with obligatory morphological markers to correspond to a picture.

The extent to which language tasks designed to assess semantic, phonological, and morphosyntactic knowledge tap a single or multiple language processing factor(s) has been assessed in only a few studies. Factor analytic studies of standardized tests of language abilities have reported multiple factors to explain the variance underlying performance (McKay & Golden, 1981; Skarakis-Doyle, Miller, & Reichheld, 2000). The *Clinical Evaluation of Language Fundamentals* (CELF-4; Semel, Wiig, & Secord, 2003) is a standardized test commonly used in clinical practice to identify language and communication disorders in children. Studies based on the normative sample for this test (Semel et al., 2003) identified a core language composite with four subfactors: expressive language, receptive language, language content, and language structure (or language memory in older groups). Importantly, the CELF-4 is an omnibus language test with multiple subtests aimed at sampling not only syntactic and semantic knowledge but also all aspects of language functioning.

In other work, considerable debate surrounds the question of the separability of morphosyntactic and semantic knowledge specifically. Using the example of English past tense, Pinker (1999) suggested that irregular words (e.g., *drank*) are stored directly with their associated meaning whereas regular words (e.g., *jumped*) must be constructed using morphological rules (e.g., add "ed"). Consistent with this "words and rules" account is evidence of processing differences in word retrieval tasks requiring or not requiring the application of a linguistic rule (Ullman et al., 1997). A preponderance of evidence from connectionist models, however, suggests that a single mechanism based on statistical learning alone is sufficient to account for the data (Joanisse & Seidenberg, 1999; Rumelhart & McClelland, 1986). Indeed, Bates and Goodman (1997) suggested that grammar and the lexicon were inseparable; they proposed a unified lexical account to explain a wide body of evidence pertaining to children's emergence of grammar and language disorders in older children and adults. Similarly, Tomblin and Zhang (2006) reported that a one-dimensional model was sufficient to account for the variance in omnibus language test performance, especially for younger children. These latter findings, then, would predict that a single language processing factor would be sufficient to explain the variance in performance on verbal tasks tapping morphosyntactic or semantic knowledge. It must be noted, however, that the semantic system encompasses more than just word meaning. It may be that, with a sufficiently comprehensive assessment, semantic knowledge itself may be shown to consist of separable components.

MEASURES OF IMMEDIATE MEMORY

Another group of verbal tasks have been designed by researchers interested in working memory, which can be defined as the ability to hold information in the current focus of attention. According to the tripartite working memory model of Baddeley and Hitch (1974), domain-specific phonological and visuospatial short-term memory stores hold relevant material for brief periods of time and have a rehearsal mechanism to increase retention (Baddeley, 1986, 2003; Logie, 1995). The third component of working memory is the central executive, a capacity-limited domain-general resource associated with attentional control, high-level processing activities, and the coordination of activities within working memory (Alloway et al., 2004; Baddeley, 1998; Baddeley, Della Salla, Gray, Papagno, & Spinner, 1997). Verbal tasks such as immediate recall of words or digits in a list would be considered to tap phonological short-term memory, whereas nonverbal tasks that involve recall of locations, such as dots on a grid, would be considered to tap visuospatial short-term memory.

In addition to short-term retention of material, working memory tasks require additional processing of information. Examples of verbal working memory tasks include judging the veracity of a sentence while retaining the last word or counting similar items and recalling the total. Such tasks are believed to be supported by both phonological short-term memory (for item retention) and the controlled attentional resources of the central executive. Corresponding visuospatial working memory tasks also tap both visuospatial short-term memory and the central executive because they involve recall of visuospatial information such as locations or orientations and visuospatial processing such as mental rotation.

Several investigations provide support for the basic structure of the tripartite working memory model by demonstrating separable factors reflecting distinct domain-specific short-term memory stores and a domain-general attentional control resource (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004). It should be noted that some studies have failed to distinguish factors corresponding to visuospatial short-term memory and the central executive (Gathercole & Pickering, 2000; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). Findings from a developmental study of working memory suggested that visuospatial short-term memory tasks may draw on executive resources or controlled attention to a greater extent than verbal short-term memory tasks, especially in younger children (Alloway, Gathercole, & Pickering, 2006). As well, executive functions have been found to support visuospatial tasks when the presentations involve dynamic rather than static images (Logie, 1995).

MEASURES OF INTELLIGENCE

A final set of verbal tasks to be considered in this article comprises those that are included in tests of intelligence (IQ). Tests of intelligence traditionally have included indicators of the ability to analyze information and solve problems using language-based reasoning (verbal IQ) or nonverbal reasoning (performance IQ). Alternatively, largely analogous indicators of crystallized and fluid intelligence have also been described (Horn & Cattell, 1967; McGrew, 2005). Crystallized intelligence is the ability to use skills, knowledge, and experience acquired in a lifetime. Fluid intelligence or fluid reasoning is the capacity to think logically and solve problems efficiently in novel situations, independent of acquired knowledge. Verbal tasks that involve application of acquired vocabulary and general knowledge are considered to tap crystallized intelligence, whereas largely nonverbal tasks requiring relational reasoning test fluid reasoning.

Theories of intelligence aim to describe the full complement of cognitive abilities. These theories typically include a single, general factor (*g*). General intelligence, or general mental ability, has been suggested to account for 40%–50% of the variance in performance on all types of cognitive tests (Kamphaus, Rowe, Winsor, & Kim, 2005). Nevertheless, factor analytic studies of intelligence have led to the proposal of a hierarchical three-stratum model known as the Cattell–Horn–Carroll (CHC) theory of cognitive development (Carroll, 1993; Cattell & Horn, 1978; McGrew, 2005). The CHC theory specifies about 70 specific or narrow abilities at Stratum 1, eight or nine second-order or broad abilities at Stratum 2, and an overall general factor at Stratum 3. In addition to crystallized intelligence and fluid reasoning, the second-order broad abilities may include quantitative reasoning, visuospatial processing, auditory processing, short-term memory, long-term storage and retrieval, and processing speed (Flanagan, Ortiz, & Alfonso, 2007). Although not specifically represented in this model, working memory has been found to be a significant predictor of *g* (Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Kane, & Tuholski, 1999). It has been suggested that working memory is an executive attentional control mechanism, variably tapping different cognitive processes represented in the model depending on task demands. In this way, working memory supports the active maintenance of goal-relevant information in the face of interference (Kane & Engle, 2000; Lustig, May, & Hasher, 2001).

RELATIONSHIPS BETWEEN VERBAL TASKS

It is clear that different motivations have led to the design of different verbal tasks to assess different cognitive abilities. However, there has been no systematic assessment of the joint variations in performance across verbal tasks commonly included in standardized tests. A better understanding of the interrelationships between these tasks is important because such findings will contribute to understanding of the cognitive processes that support them. This study explored the principal components necessary to explain the variation in performance across tasks from standardized tests of language, working memory, and intelligence. Because of practical constraints, it was not possible to include an adequate sampling of all of the tasks considered to tap, for example, language or crystallized intelligence. Nevertheless, at least two measures were included that were considered to tap language, phonological short-term memory, visuospatial short-term memory, working memory, crystallized intelligence, and fluid reasoning. Accordingly, the main question addressed by this study concerned whether there was evidence for the separability of demands related to language, short-term memory, working memory, and intelligence across this range of tasks. The study was not designed to investigate the structure of the variation within each domain, for example, within the domains of language (e.g., morphology, syntax).

Although the interrelationships between verbal tasks tapping this range of abilities have not been systematically assessed previously, findings of studies assessing links between some of these measures provide relevant information regarding the potential separability of these processes. For example, close and specific associations have been found between a phonological short-term memory measure known as nonword repetition involving the immediate repetition of novel, multisyllabic words, and one aspect of language, vocabulary knowledge (Gathercole, Service, Hitch, Adams, & Martin, 1999).

The relationship between nonword repetition and vocabulary is strongest during the early stages of vocabulary development in both native (Gathercole, Willis, Emslie, & Baddeley, 1992; Masoura & Gathercole, 2005) and foreign language acquisition (Masoura & Gathercole, 2005). It has been suggested that phonological short-term memory is particularly important to new word learning early in vocabulary development when there is little available support from existing lexical knowledge (Gathercole, 2006). This notion would lead to the prediction that phonological short-term memory and amassed lexical knowledge should be separable factors exerting unique influences on performance depending on the demands of the task.

Strong positive links have been demonstrated between the domain-general central executive component of working memory and aspects of sentence-level language processing, including measures of comprehension (Gathercole, Durling, Evans, Jeffcock, & Stone, 2008) and production (Adams & Gathercole, 1995). Working memory, rather than short-term memory, has been implicated in these studies because the memory tasks used have imposed verbal processing demands in addition to the brief retention of phonological information.

Working memory may be expected to support language functioning, given the multiple demands of verbal communication, such as the need to translate thoughts and ideas rapidly to verbal codes, produce well-formed discourse, and negotiate social nuances. The relationship between working memory and language would not be expected to be specific, however. Indeed, working memory has been found to be linked to a number of other complex cognitive activities including mental arithmetic (DeStefano & LeFevre, 2004) and scholastic achievement (Bayliss et al., 2003). These findings would suggest the hypothesis that domain-general working memory and language processing may be separable but related factors influencing language functioning. It should be noted that no association has been found between measures of visuospatial short-term memory and language (Adams, Bourke, & Willis, 1999) except when spatial language (e.g., above, below) is tested specifically (Phillips, Jarrold, Baddeley, Grant, & Karmiloff-Smith, 2004).

The extent to which the influence of one aspect of intelligence, crystallized intelligence, may be separable from more specific language processing involving morphosyntactic or semantic knowledge is unclear. Arguably, crystallized knowledge may subsume both morphosyntactic abilities and semantic knowledge. Indeed, descriptions of crystallized intelligence include knowledge and application of the grammatical features of the language, as well as lexical and general knowledge (McGrew, 2009). As such, any distinction between language processing and crystallized intelligence is subtle, and the design of specific tasks to measure one but not the other is challenging. As a result, it may be very difficult to separate these factors empirically except in extremely large studies with multiple measures.

THIS STUDY

This study explored the interrelationships between standardized measures of language, working memory, and intelligence in a sample of nearly 400 school-aged children. All verbal tasks involving language processing such as understanding a sentence or defining a word were expected to load on a single-language processing factor, given their overlapping verbal demands. Nevertheless, a separate component corresponding to those tasks tapping application of general knowledge (e.g., defining a word) would distinguish a crystallized intelligence factor from the language processing factor. It was further hypothesized that tasks involving verbal retention would pose different demands than those involving language processing, leading to the identification of a phonological short-term memory factor distinct from the language processing factor. A single domain-general working memory factor was predicted to reflect performance on tasks involving immediate information processing and retention across both verbal and visuospatial domains. Tasks imposing both working memory and language demands were expected to have a complex loading pattern, with variance explained by both the language processing and domain-general working memory factors. A fluid reasoning factor was predicted to account for performance on traditional nonverbal intelligence tasks requiring solving of novel problems, and a visuospatial short-term memory factor was expected to explain variability on the tasks requiring recall of visuospatial information.

A second aim of the study was to examine the relationship between latent variables identified in the factor analysis and other nonstandardized verbal tasks including grammatical judgment, sentence recall, and rapid automatic naming (RAN). Grammaticality judgment, a task requiring the judgment of the grammatical accuracy of a sentence, clearly taps language processing. However, the task also requires retention of the sentence while assessing or comparing different aspects of the sentence. As such, grammatical judgment tasks may also impose working memory demands. Sentence recall chiefly requires short-term retention of the phonological form of the sentence. Nevertheless, language processing can be expected to be recruited as an obligatory process in sentence recall tasks. Rapid automatic naming, a measure of how quickly individuals can name familiar objects or letters, imposes language processing and other additional demands. Critical aspects of RAN include the need for focused sustained attention over time (Wolf, Bowers, & Biddle, 2000) and the dynamic cognitive suppression of previous and upcoming responses (Arnell, Joanisse, Klein, Busseri, & Tannock, 2009). It has been suggested that efficient coding in working memory may account for unique variance in RAN performance (Arnell et al., 2009), as would retrieval from long-term memory and processing speed.

METHODS

Participants

Data from 374 children (199 boys) aged 5 years 0 months to 9 years 11 months were drawn from our existing database in this study (see Supplemental Digital Content Appendix A, available at: http://links.lww.com/TLD/A21). The database was developed in two parts described in detail elsewhere (Archibald, Oram Cardy, Joanisse, & Ansari, 2013). Briefly, all children in senior kindergarten to Grade 4 were invited to participate from 34 area schools in the southwest region of Ontario, Canada. A total of 1,387 children completed three screening tasks measuring language (sentence recall, see below), reading (*Test of Word Reading Efficiency*; Torgensen, Wagner, & Raschotte, 1999), and math (math fluency from the *Woodcock-Johnson III Test of Achievement*; Woodcock, McGrew, & Mather, 2001). A subset of this group ($n = 374$), representing a range of abilities on the screening measures, completed the measures reported here.

Procedures

Within 6 months of the initial 10-min screening visit, all participants completed a comprehensive test battery over three 30- to 40-min study visits occurring approximately 1 week apart. The test battery included standardized tests of language, short-term and working memory, and verbal and nonverbal intelligence, as well as nonstandardized measures of rapid picture naming, rapid letter naming, grammaticality judgment, and other tasks not reported here. The sentence recall task was completed during the screening visit. All tasks were administered individually in a quiet room in the child's school by a trained research assistant.

Standardized test battery

Language

Each child completed the four core subtests appropriate for the child's age for the Composite Language Score from the CELF-IV (Semel et al., 2003). In the concepts and following directions subtest, the child pointed to aspects of a picture following a spoken instruction. For recalling sentences, the child repeated sentences immediately after hearing them, and for formulated sentences, created a sentence using a given word. Children younger than 9 years completed the word structure subtest, which involves completing a sentence with the grammatically correct word form, and those 9 years and older completed the word classes 2 subtest, which involves identifying which two of four words have a related meaning. Scaled and standard scores were based on published test norms.

Verbal and visuospatial short-term and working memory

Eight subtests from the Automated Working Memory Assessment (Alloway, 2007) were administered. Measures tapping phonological short-term memory involved immediate repetition of numbers or nonword forms (digit recall, nonword recall), and those tapping visuospatial short-term memory required recall of locations (dot matrix, block design). Verbal working memory measures involved recall of counts or final words after counting or processing a sentence (counting recall, listening recall), respectively, whereas those involving visuospatial working memory required the recall of location or orientation after identifying a different shape or mentally rotating an image, respectively (odd one out, spatial recall). Standard scores were based on published test norms.

Verbal and nonverbal intelligence

Children 6 years and older completed the four subtests of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), and those younger than 6 years completed six subtests from the Wechsler Preschool and Primary Scale of Intelligence, Third Edition (WPPSI-3; Wechsler, 2002). The nonverbal intelligence subtests included block design, in which children arranged blocks to match a model, and matrix reasoning, which involved choosing a picture to complete a pattern; for children younger than 6 years, picture concepts, in which children picked pictures that go together. The verbal intelligence subtests included vocabulary, in which children provided definitions, and similarities, which involved identifying related pictures or describing similarities between words; for children younger than 6 years, information, in which children provided general world knowledge such as the color of grass. *T* scores from the WASI and scaled scores from the WPPSI published test norms were converted to standard scores ($M = 100$; $SD = 15$).

Nonstandardized measures

Rapid naming

Two RAN tasks were administered, the first involved naming of four letters (*g*, *k*, *m*, and *r*), and the second, naming of common pictures (*book*, *dog*, *chair*, and *hand*). To familiarize the child with the items, an 11 in. × 8.5 in. paper with a single row of stimuli including one copy of each of the items in the task was presented for the child to name. The RAN task for the respective stimuli set was presented immediately after this. Items were presented in a five-row × 10-column grid on a standard 11 × 8.5 in. paper. The children were instructed to name each stimulus item accurately as quickly as possible, beginning at the top left corner and proceeding along each row to the bottom right. Any naming errors were recorded by the administrator. The time required in seconds to name all the items in the grid was recorded for each task (pictures; letters).

Grammaticality judgment

In the grammaticality judgment task, the child was asked to decide whether an auditorily presented sentence sounded correct ("sounds like something a person would really say") or incorrect ("sounds funny or wrong"). The task was derived from the grammaticality judgment task used by Miller, Leonard, and Finneran (2008) and has been described in detail in Noonan, Redmond, and Archibald (2013). Sentences consisted of 24 sentences with a mean length of 10.95 words ($SD = 0.91$). Twelve sentences were grammatically correct (e.g., "You must stir your gravy so it doesn't become too lumpy"; participant response: "yes"), and 12 sentences contained a grammatical error (e.g., "Joan bikes and **skate* in the park every day after school"; participant response: "no"). Sentences were presented via a digital audio recording of an adult female speaker in fixed random order on a laptop computer. Each child's "yes" or "no" response was recorded online and scored offline as the total number correct (out of 24).

Sentence recall

The sentences were taken from Redmond (2005) and consisted of 16 sentences, each composed of 10 words (10–14 syllables), with an equal number of active and passive sentences. Although not standardized, this task has been found to have good sensitivity and specificity for identifying children with language impairment (Archibald & Joanisse, 2009). The sentences were presented in fixed order via a digital audio recording of an adult female speaker, using headphones. Sentences were scored online by the research assistant as 2 (correct), 1 (three or fewer errors), or 0 (more than four errors or no response).

RESULTS

Interrelationships between language, memory, and intelligence measures

Appendix A (see Supplemental Digital Content, available at: http://links.lww.com/TLD/A21) presents descriptive statistics for all participants grouped by chronological age. There was a significant developmental increase in raw scores, $F > 7.1$, $p < .001$, $\eta^2_p > .07$ (all cases, except nonword recall: $F(4, 369)$, $p = .031$, $\eta^2_p > .03$). Given the wide age range of the sample, all analyses involving the standardized tests were completed on the age-adjusted scores (scaled for the language subtests; standard scores for all remaining tests). Correlations examining the relationships between the language, intelligence, and short-term and working memory measures completed by all participants revealed significant correlations in all (but one) cases, $r \geq .12$, $p < .05$ (see Supplemental Digital Content Appendix B, available at: http://links.lww.com/TLD/A20). Although the large sample size may have increased the chance of reaching significance, 68% of the correlations were at or above the .3 level conventionally considered to have practical significance (Cohen, Cohen, West, & Aiken, 2002).

To examine the underlying structure in these data, an exploratory factor analysis was performed. A principal components analysis was performed on the data from the language, intelligence, and short-term and working memory tests completed by all participants (i.e., excluding word structure, word classes, information, and picture concepts, which were each completed by a subset of participants depending on age). Five factors met Jolliffe's (1972) criterion that factors with eigenvalues greater than 0.7 be retained. Nevertheless, the five-factor solution resulted in one trivial factor defined as a factor with only one variable loading above .3 (Comrey & Lee, 1992). As a result, four factors were retained with eigenvalues of 5.8, 1.6, 1.3, and 0.8, respectively, which, together accounted for 63.5% of the total variance. A varimax rotation was performed to enhance the interpretation of the factors. The rotated component matrix factor loadings for each of the 15 measures are given in Table 1, together with the percentage of variance explained in the rotated solution by each factor. Factors 1 and 2 each account for approximately 20% of the variance, respectively, and factors 3 and 4, 10%–13%.

Factor 1 shows high loadings (>.5) for all of the verbal and visuospatial working memory tasks and the visuospatial short-term memory measures. The concepts and following directions subtest also show a considerable secondary loading (>.3) on this factor. Taken together, this pattern reflects domain-general processing in the context of immediate memory demands, and as such, this factor may be considered a working memory factor. Factor 2 is associated with high loadings for all of the language subtests and the verbal intelligence subtests. The listening recall working memory task and the matrix reasoning subtests show minimal secondary loadings

Table 1. Factor loadings (>.25) for the exploratory factor analysis for the entire sample ($n = 374$) with varimax rotation

	Component			
	1	2	3	4
Digit recall			.77	
Nonword recall			.75	
Dot matrix	.76			
Block recall	.74			
Listening recall	.51	.28	.50	
Counting recall	.63		.38	
Odd one out	.68		.26	
Spatial recall	.73			
Concepts and FD	.38	.66		
Recalling sentences		.68	.51	
Formulating sentences		.78		
Vocabulary		.75		
Similarities		.69		.26
Block design				.81
Mazes reasoning		.26		.80
% variance explained	21	19	10	13

Note. FD = following directions.

(.25–.3) on this factor. This suggests that Factor 2 is a language factor involving domain-specific verbal processing. Factor 3 shows high loadings for digit recall, nonword recall, recalling sentences, and listening recall. Counting recall shows a considerable secondary loading whereas odd-one-out loads minimally on factor 3. All of these tasks, with the exception of odd-one-out task, explicitly involve verbal storage of digits or words, suggesting that Factor 3 is a phonological storage factor. Finally, Factor 4 is associated with the block design and matrix reasoning subtests with a minimal loading of the similarities subtest. Thus, Factor 4 may be considered a nonverbal or fluid reasoning factor.

Developmental patterns in the factor structure

To examine the development of these factors, the sample was split into a younger versus older groups on the basis of the median age of 91 months (7 years 7 months). Children younger than 91 months (7 years 6 months or younger) constituted the younger group (n = 183), whereas those 91 months or older (older than 7 years 6 months) formed the older group (n = 191). For both of these groups, the sample size exceeded the recommended minimum for factor analysis of 10 observations per variable (Nunnally, 1978). The principal components analysis completed on the younger group included all of the 15 variables present in the previous analysis, as well as the scores for the word structure subtest completed by all participants in this group. The four-factor solution resulted in factors with eigenvalues of 5.9, 1.7, 1.4, and 1.0, respectively, which together accounted for 63% of the total variance. The rotated component matrix factor loadings for each of the 16 measures are given in Table 2, together with the percentage of variance explained in the rotated solution by each factor. Factors 1 and 2 each account for 19% of the variance, and Factors 3 and 4, 12%–13%.

Factor 1 is associated with high loadings of all of the language subtests (including word structure) and the vocabulary subtest. The digit recall, listening recall, and similarities test show considerable secondary loadings. This suggests that Factor 1 is a language factor involving domain-specific verbal processing, corresponding to the second factor in the analysis of the entire sample. Factor 2 shows high loadings for three of the four working memory tasks, with the remaining verbal working memory task, counting recall, showing considerable secondary loadings. As well, the concepts and following directions and word structure subtests have considerable secondary loadings on this factor. This pattern is consistent with that seen for Factor 1 in the entire sample and suggests that Factor 2 in the younger sample is a working memory factor. It should be noted that the variance explained in the rotated solution for Factors 1 and 2 was 19% for each and thus the reversal of the working memory and language factors relative to the entire sample may not be meaningful. Factor 3 shows high loadings

Table 2. Factor loadings (>.25) for the exploratory factor analysis for the younger sample (n = 183) with varimax rotation

	Component			
	1	2	3	4
Digit recall	.33		.69	
Nonword recall			.78	
Dot matrix		.76		
Block recall		.70		.26
Listening recall	.32	.51	.51	
Counting recall		.48	.53	.31
Odd one out		.59	.36	.29
Spatial recall		.75		
Concepts and FD	.64	.44		
Recalling sentences	.74		.44	
Formulating sentences	.76			
Vocabulary	.65			.33
Similarities	.43			.61
Block design				.63
Mazes reasoning				.79
Word structure	.70	.39		
% variance explained	19	19	13	12

Note. FD = following directions.

for digit recall, listening recall, and counting recall and considerable secondary loadings for recalling sentences and odd one out. As in the previous analysis, all of these tasks with the exception of the odd-one-out task explicitly involve verbal storage of digits or words, suggesting that Factor 3 is a phonological storage factor. Factor 4 is associated with the block design, matrix reasoning, and similarities subtests, with considerable secondary loadings of the vocabulary and counting recall subtests and minimal loadings of the odd-one-out subtest. As before, Factor 4 may be considered a fluid reasoning factor; however, the factor is not strictly nonverbal in this younger group, as both verbal and nonverbal tasks load on the factor.

The corresponding four-factor solution for the older group resulted in factors with eigenvalues of 6.1, 1.6, 1.1, and 0.8, respectively, which together accounted for 64% of the total variance. The rotated component matrix factor loadings for each of the 15 measures completed by all participants are given in Table 3, together with the percentage of variance explained in the rotated solution by each factor. Factors 1 and 2 individually account for approximately 20% of the variance, respectively, and Factors 3 and 4, 10%–13%. The factor structure and pattern of loadings exactly mirrored those for the entire sample. Factor 1, the working memory factor, shows high loadings for all of the verbal and visuospatial working memory tasks and the visuospatial short-term memory measures, with a considerable secondary loading of the concepts and following directions subtest. Factor 2, the language factor, is associated with high loadings of all of the language subtests and the verbal intelligence subtests. The listening recall working memory task and the matrix reasoning subtests show minimal secondary loadings on this factor. Factor 3, the phonological storage factor, shows high loadings for digit recall, nonword recall, and recalling sentences, with considerable secondary loadings for listening recall and odd-one-out and minimal loading of counting recall. Finally, Factor 4 is associated with the block design and matrix reasoning subtests. The similarities subtest does not show a minimal loading on this factor. Thus, Factor 4 may be considered a fluid reasoning factor, with only nonverbal tasks loading on the factor.

Table 3. Factor loadings (>.25) for the exploratory factor analysis for the older sample ($n = 191$) with varimax rotation

	Component			
	1	**2**	**3**	**4**
Digit recall			.81	
Nonword recall			.63	
Dot matrix	.75			
Block recall	.75			
Listening recall	.50	.27	.46	
Counting recall	.74		.29	
Odd one out	.71		.31	
Spatial recall	.70			
Concepts and FD	.33	.69		
Recalling sentences		.63	.59	
Formulating sentences		.76		
Vocabulary		.75		
Similarities		.75		
Block design	.26			.83
Mazes reasoning		.28		.79
% variance explained	22	20	13	10

Note. FD = following directions.

To summarize the factor analyses, factors corresponding to working memory, language processing, phonological storage, and nonverbal fluid reasoning explained 63% of the variance in language tasks and verbal and nonverbal short-term memory, working memory, and intelligence measures in a sample of 374 children aged 5 years 0 months to 9 years 11 months. There were some notable differences in the loadings for each variable across these four factors for the younger versus older groups. The greatest differences were for the fluid reasoning factor, which included loadings for the two nonverbal intelligence measures only for the older group. For the younger group, however, the fluid reasoning factor also included some loading from several other variables (both verbal intelligence measures, counting recall, odd one out, block recall). The older and younger groups also differed in the proportion of variance in performance (as reflected by squared factor loadings) explained for some tasks. For the older group, the majority of the variance (54%) in counting recall was explained by the working memory factor (compared with 8% by the phonological storage factor), whereas counting recall performance was explained relatively equally by both the working memory (23%) and phonological storage factors (27%) for the younger group. Digit recall loaded on the phonological storage factor for both groups (47% and 65% of the variance explained for the younger and older groups, respectively), but a proportion of the variance was also explained by the language processing factor for the younger group (11%). Variance in recalling sentences was explained relatively equally by the language processing (40%) and phonological storage factors (35%) for the older group but had higher loadings on the language processing (55%) than phonological storage factors (20%) for the younger group. In addition to loading on the working memory factor for both groups (25%–26% of variance explained), listening recall was associated with somewhat higher loadings on the language processing and phonological storage factors for the younger (36% total for both factors) than older group (28%).

Relationships between identified factors and related cognitive measures

Both by way of validating the identified factors and by examining their relationship to related measures, correlations were computed between the factor scores and the rapid object naming, rapid letter naming, grammatical judgment, and sentence recall tasks separately for the entire sample and for the younger and older groups. Table 4 presents the three correlation matrices. For the entire sample, the working memory factor was moderately correlated with the rapid

Table 4. Correlations between the identified factors and four nonstandardized measures for the entire sample and for the younger and older groups

	Nonstandardized Measures			
Factors	**RAN Objects**	**RAN Letters**	**Grammaticality Judgment**	**Sentence Recall**
Entire sample ($n = 374$)				
Working memory	−.15**	−.13*	−.04	.02
Language	−.24**	−.22**	.33**	.47**
Phonological storage	.07	.08	.05	.12*
Fluid reasoning	−.08	−.11*	.21**	.18**
Younger group ($n = 183$)				
Working memory	−.08	−.07	−.10	−.02
Language	−.20**	−.23**	.25**	.42**
Phonological storage	−.04	−.05	.06	.17*
Fluid reasoning	−.22**	−.28**	.19*	.34**
Older group ($n = 191$)				
Working memory	−.23**	−.27**	.04	.02
Language	−.26**	−.27**	.43**	.51**
Phonological storage	−.08	−.08	.16*	.37**
Fluid reasoning	−.11	−.01	.28**	.18*

Note. RAN = rapid automatic naming.
*$p < .05$; **$p < .01$.

naming but not the grammaticality judgment or sentence recall tasks. The relationship with the rapid naming tasks was stronger in the older group and not significant in the younger group. In contrast, the fluid reasoning factor was strongly correlated with the rapid naming tasks for the younger age group but not for the older age group, resulting in mixed results for the entire sample (moderate correlation for one rapid naming task but not the other). The language factor was correlated with all measures in all of the analyses, whereas the phonological storage factor was correlated with the sentence recall task in all cases and with the grammaticality judgment task only for the older group. It must be acknowledged that the correlations between the nonstandardized sentence recall task and the language and phonological short-term memory factors are not surprising, given that one of the subtests contributing to both of the latter two factors was the recalling sentences subtest of the CELF-4 (Semel et al., 2003). Nevertheless, inclusion of the correlations with the nonstandardized sentence recall task contributes to the overall pattern of the results.

DISCUSSION

This study examined the factors and interrelationships underlying traditional measures of language, short-term and working memory, and verbal and nonverbal intelligence in children. Four factors were found to best explain variance in performance on these measures: a working memory factor characterized by domain-general processing in the context of immediate memory demands, a language factor involving domain-specific verbal processing, a phonological storage factor, and a fluid reasoning factor. Corresponding analyses based on younger and older halves of the data revealed some interesting developmental patterns in these factors. Generally, more variables loaded on the fluid reasoning factor for the younger group than for the older group. As well, a greater proportion of the variance on several verbal tasks was explained in the younger group than in the older group by either the language processing factor (digit recall, recalling sentences, listening recall) or the phonological storage factor (counting recall, listening recall). Of the nonstandardized rapid naming, grammaticality judgment, and sentence recall measures, the language factor was associated with all, regardless of age. Rapid naming additionally correlated with working memory in the older group and with fluid reasoning in the younger group. Phonological storage was consistently linked with sentence recall regardless of age and with grammaticality judgment in the older group.

This study provides evidence that significant variability in children's performance on common verbal tasks included in standardized tests is explained by separable factors related to domain-general working memory, language processing, phonological short-term memory, and, depending on age, fluid reasoning. The current results are consistent with the tripartite working memory model (Baddeley & Hitch, 1974) distinguishing a domain-general processing component corresponding to the central executive and a domain-specific phonological short-term memory component corresponding to the phonological loop (Bayliss et al., 2003; Engle et al., 1999; Kane et al., 2004).

As predicted, verbal tasks requiring only retention without additional information processing loaded on the phonological short-term memory factor. Verbal recall tasks with added processing demands also loaded on the domain-general working memory factor together with corresponding nonverbal visuospatial tasks. The distinction between a phonological short-term storage mechanism supporting brief verbal recall and an additional resource supporting immediate processing of verbal information is indicated by the pattern of loadings on these factors for the other language tasks included in the analyses. For example, recalling sentences places high demands on storage and loaded on the phonological short-term memory factor, whereas following directions requires some immediate processing of verbal information and loaded on the domain-general working memory factor. Similarly, the nonstandardized sentence repetition task correlated with the phonological short-term memory factor whereas the rapid naming tasks requiring dynamic cognitive activation and suppression correlated with the working memory factor. Of less interest to this study was the lack of a factor corresponding to visuospatial short-term memory specifically. As has been suggested in previous studies (Alloway et al., 2006; Gathercole & Pickering, 2000; Logie, 1995; Miyake et al., 2001), it may be that the act of briefly maintaining visuospatial information in dynamic tasks such as those in this study imposed processing demands, at least for our young participants.

Interestingly, this study is one of the first to provide evidence of the separability of domain-general working memory and language processing factors. Contrary to suggestions that verbal working memory and linguistic measures tap a unitary language processing construct (MacDonald & Christiansen, 2002), tests and nonstandardized measures involving verbal information processing loaded on, or correlated with, one or both factors in this study. The tasks loading on the domain-general working memory component required the immediate processing of relatively simple verbal information while holding some material in mind. For example, the listening recall task requires true or false judgments about short sentences made up of frequent words and tapping common knowledge as in "Lions have four legs." The concepts and following directions language test also loaded on the domain-general working memory factor to some extent. At least some of the items in this subtest rely on the processing of familiar concepts and vocabulary and require retention of several items such as "Point to the second black shoe and the third white ball." Finally, the rapid naming tasks also correlated with the working memory factor.

Tasks requiring the processing of linguistic relationships loaded on a language processing factor separate from the domain-general working memory factor. All tasks involving some processing of linguistic relationships loaded on this factor including understanding a simple sentence, following directions, identifying commonalities between words, formulating a sentence given a word, and giving the definition of a word. The latter two tasks required the expression of complex language and were the only tasks to load solely on the language processing factor.

Interestingly, the recalling sentences test loaded on the language processing factor, suggesting that sentence repetition involves sentence processing and retention. Converging evidence that semantic processing supports recall comes from findings of more accurate recall of words than nonwords (Hulme, Maughan, & Brown, 1991), related than unrelated word lists (Poirier & Saint-Aubin, 1995), and story-based than unrelated sentence lists (Jeffries, Lambon Ralph, & Baddeley, 2004). Additional evidence of the separability of the language processing and working memory factors was the results of the correlations with the nonstandardized tasks. In particular, grammaticality judgment was correlated with the language but not working memory factor, showing a distinct relationship to language processing but not domain-general working memory. It may be that this pattern of findings informs MacDonald and Christiansen's (2002) notion that language processing is not supported by a capacity-limited working memory resource. In particular, the present results indicate that nontrivial language processing tasks without specific storage demands are supported by a language processing factor but not a working memory factor.

The language processing factor was found to be distinct from the phonological short-term memory factor in this study as well. Tasks requiring the retention of verbal information processing but no additional information processing such as digit recall and nonword recall loaded only on the phonological short-term memory factor. Tasks with additional processing demands also loaded on another corresponding factor, the language processing factor for tasks requiring processing of linguistic relationships such as listening recall and recalling sentences and the working memory factor for those requiring immediate domain-general processing such as odd one out and counting recall.

Phonological short-term memory has been closely linked to language learning. Consistently, children with an unexplained language learning deficit known as specific language impairment (SLI) have been found to have a phonological short-term memory deficit (Archibald & Gathercole, 2006; Archibald & Joanisse, 2009). Nevertheless, a phonological short-term memory deficit alone has not been found to lead to a lasting language learning impairment (Gathercole, Tiffany, Briscoe, Thorn, & ALSPAC Team, 2005). Gathercole (2006) suggested distinct roles in the learning of new words forms for both phonological short-term memory and long-term memory for language content, with the former being important to the brief retention of unfamiliar phonological forms and the latter supporting learning when new information activates existing representations. Interestingly, the nonstandardized grammatical judgment task correlated with the language processing factor as expected, but it showed only a weak relationship with phonological short-term memory in the older group. It may be that the task did not place sufficient demands on short-term memory skills or only taxed immediate memory in some participants (see Noonan et al., 2013).

This study failed to distinguish a language processing from a crystallized knowledge factor, with both language and verbal intelligence tasks loading on the same factor. Although this result might suggest a unitary long-term language knowledge and processing factor, the finding may be related to the limited range of language processing tasks included in this study. For example, no specific grammatical tests administered to all participants were included in the analysis. Given that a grammatical learning deficit has been suggested as a hallmark of SLI (Rice, 2003), the extent to which grammatical learning can be distinguished from other types of language processing in a large developmental group requires further investigation. The language processing factor was distinguished from a fluid reasoning factor in this study. Only the two nonverbal intelligence measures consistently loaded highly on this factor. The correlations between the fluid reasoning factor and the nonstandardized grammaticality judgment and sentence recall tasks may have arisen due to shared variance with the other factors.

The current findings provide some preliminary indications of developmental changes in the cognitive processes supporting the verbal tasks in this study. For example, digit recall loaded on the language processing factor for the younger group but not the older group. As well, more variance was explained for the listening recall and sentence recall tasks by the language processing factor for the younger group than the older group. These findings may reflect the diminishing language processing demands imposed by these tasks as linguistic competency improves. The counting recall task, and to some extent, the listening recall task loaded more strongly on the phonological short-term memory factor for the younger group than the older group. It has been suggested that developmental increases in working memory tasks such as these occur due to the more efficient encoding and rehearsal of items enabled by growing improvements in linguistic abilities (Flavell, Beach, & Chinsky, 1966; Ottem, Lian, & Karlsen, 2007).

It follows from these results that the storage demands of working memory tasks constrain performance to a greater extent in younger children than in older children. Nevertheless, the primary factor identified for the younger group was the language processing factor whereas the primary factor for the older group was the working memory factor. This reversal may reflect the developing nature of the linguistic system for the younger group and the importance of working memory once language abilities are largely intact for the older group.

Finally, more variables loaded on the fluid reasoning factor for the younger group than for the older group, including both verbal (counting recall; vocabulary) and nonverbal tasks (odd one out; block recall). Similarly, the nonstandardized rapid naming tasks were correlated with the fluid reasoning factor in the younger group and the working memory factor in the older group. To our knowledge, these findings are the first to suggest that performance on working memory tasks may be supported by different cognitive processes in younger children than in older children. Specifically, such tasks may be particularly novel to young children, leading to the recruitment of fluid reasoning for younger children than for older children.

Clinical implications

The current results have important clinical implications for assessing the verbal abilities of children with language learning difficulties. Measures commonly used in standard language batteries include following directions, repeating sentences, and formulating a sentence from a given word, and questions often arise regarding the extent to which these tasks tap cognitive processes additional to language. The findings from this study suggest that these language tasks primarily tap a language processing factor separable from both working memory and phonological short-term memory. It is important to remember, however, that deficits in the latter two processes could affect performance on these language tasks.

Study limitations

One of the main limitations of this study is the small number of tasks corresponding to each of the hypothesized constructs being investigated. In addition, the sample size was relatively small for an investigation of this nature. As well, the factor structures may have been influenced by the tests and subtests used. However, any relationship between factors and tests was not direct in that some measures did span a number of factors and some factors included loadings of subtests from more than one test. Overall, the findings provide a useful exploration of the underlying processes supporting verbal tasks commonly used in various standardized tests purporting to tap different cognitive mechanisms.

CONCLUSION

A large sample of school-aged children completed standardized verbal tasks designed to measure language abilities, phonological short-term memory, visuospatial short-term memory, working memory, crystallized intelligence, and fluid intelligence. They also completed nonstandardized grammatical, naming, and recall tasks. A four-factor structure explained 63.5% of the variance on the standardized tests, with separable factors corresponding to domain-general working memory, language processing, phonological short-term memory, and fluid reasoning. The performance on some measures was explained to a greater extent by the language processing, phonological short-term memory, and fluid reasoning factors for younger children than for older children. These results were suggested to reflect a developmental change in the processes tapped by these measures.

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