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The Mediating Role of Receptive Language in the Relationship between Verbal Memory and Language Production in Preschool Children

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THE MEDIATING ROLE OF RECEPTIVE LANGUAGE IN THE RELATIONSHIP BETWEEEN VERBAL MEMORY AND LANGUAGE PRODCUTION IN PRESCHOOL CHILDREN

by

ANJALI VAN DRIE

Under the Direction of (Byron Robinson)

ABSTRACT

Research has demonstrated a close relationship between verbal short-term (STM) and working memory (WM) and receptive language in children (Baddeley, Gathercole, & Papagno, 1998; Ellis & Sinclair, 1996). Few studies have examined the relationship between memory and language production, and these studies focus on STM only. Though correlations have been found between verbal STM and production, the nature of the correlations are unclear. The current study examined the possibility that receptive language mediates the relationship between memory and language production. Children between 3;0 and 5;11 were administered tests assessing receptive vocabulary, receptive grammar, expressive vocabulary, verbal STM, and verbal WM. Additionally, transcripts from free-play sessions were used to assess grammar production. A regression based analytic approach revealed STM and WM mediate the relationship between receptive language and productive language. The existence of these mediated relationships are discussed in relation to the role of working memory in the speech output buffer.

INDEX WORDS: Short-term memory, Working memory, Receptive language, Expressive language, Preschool children, Speech output buffer

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Working memory (WM) and short-term memory (STM) are involved critically in many forms of complex cognitive processes. WM has been implicated in skills such as problem solving, intelligence, nonverbal reasoning, the ability to follow directions, and complex learning (Engle, 2002; Gathercole, 1999). STM has been related to areas such as intelligence, problem solving, and mathematical ability (Gathercole, 1999). Whereas these two constructs of memory are correlated positively with similar cognitive processes, they are considered separate constructs (Engle, 2002). Researchers currently debate an exact definition of WM but agree that WM functions to store and process information (e.g., Baddeley, 2003; Just & Carpenter, 1992; Engle, 2002). Because of this dual ability, often WM is conceptualized as a mental workspace functioning to carry out complex processes. STM, in contrast, is defined solely as a temporary memory store that is absent of a processing component (Baddeley, 1986).

Research suggests that the capacity of STM as well as that of WM increases with age (Case, Kurland, & Goldberg, 1982; Cowan, 1997; Gathercole & Baddeley, 1993). STM capacity, measured by assessing the number of items one can hold temporarily, increases from being able to hold two digits at age two up to seven digits by adolescence (Case et al., 1982). Preschool age children typically hold between 3 and 5 items in short-term memory depending on the measures used (e.g., Adams and Gathercole, 1995; Gathercole & Baddeley, 1989). WM capacity, assessed by using storage and manipulation tasks, also increases with age, with growth in the number of items that can be held lagging behind STM capacity slightly. WM span is typically two units lower than concurrent STM span ranging from zero to three items in preschool age children (Pascual-Leone, 2000).

Theorists debate as to what causes the increases in STM and WM across childhood (e.g., Brown, Vousden, McCormack, & Hulme, 1999; Cowan, Wood, & Wood, 1998; Gathercole & Hitch, 1993). A number of changes that occur in childhood, such as changes in perceptual analysis, retention of order information, rehearsal, and retrieval are often cited as reasons behind improvement on STM tasks in children (Gathercole, 1999). Age changes in WM performance are thought to be a result of increases in processing efficiency, attentional capacity, and the ability to task switch. Older children also are able to utilize memory strategies and techniques to improve their performance on STM and WM tasks, whereas younger children have not developed the metacognitive skills necessary to do so (Lutz & Sternberg, 1999). Many of the skills that are considered to underlie the improvements on STM and WM tasks are also attributed directly to STM and WM. That is, tasks assessing STM or WM may require a child to retain the order of information, or to switch attention between tasks. It remains unclear if the skills referred to lead to improvements in STM and WM performance, or if the skills are a part of STM and WM.

The skills that have been discussed (e.g., task switching, retrieval, retention of order information), whether they are the cause of improvements in STM and WM or whether they are parts of STM and WM, are the same skills that are needed for children to learn language. Typically, as children enter into language use, they progress from the prelinguistic period in which cooing and babbling occur to the acquisition of words, which generally begins with protowords, or sound sequences that have relatively consistent meaning but may not be real words (Gleason, 2001). Later children will advance into two word utterances, telegraphic speech, and multi-word utterances, eventually becoming competent language users. In order to attain this end goal, however, children must learn all the nuances that are involved in language comprehension and production, including intonation and stress patterns of words and utterances, morphology, conceptual relations, and semantic relations. Preschool age children typically have progressed beyond two-word utterances and are combining words and phrases into multiword utterances. It is at this stage that the other aspects of language (e.g., stress patterns, relations between words and phrases) become more important for mastery. Each of these pieces of language learning involve aspects of STM or WM to a degree. Research examining these relations between language and memory begins in childhood and continues throughout adulthood, focusing primarily on comprehension (Daneman & Carpenter, 1980; Ellis & Sinclair, 1996; Gathercole & Baddeley; 1989; Williams & Lovatt, 2003).

The ability to hold information temporarily or simultaneously hold and process information has been found to correlate with language comprehension and production in adults and children (e.g., Blake, Austin, Cannon, Lisus, & Vaughan, 1994; Daneman & Carpenter, 1980; Gathercole & Baddeley, 1989; Service, 1992; Williams & Lovatt, 2003). The findings concerning the relationship between aspects of memory and language will be briefly presented followed by a more detailed examination of the specific studies while addressing theoretically relevant models of speech production.

In adults, aspects of verbal STM and aspects of verbal WM have been related to facets of foreign language learning such as vocabulary acquisition and vocabulary comprehension (e.g., Williams & Lovatt, 2003) as well as the acquisition and comprehension of grammatical forms (e.g., Service, 1992). STM and WM memory capacities also are correlated positively with adult's sentence comprehension in native languages (e.g., Daneman & Carpenter, 1980; Norman, Kemper, & Kynette, 1992). Sentence comprehension involves maintaining and processing a sequence of related concepts perceived over time, which necessitates skills such as those involved in WM (Just & Carpenter, 1992). WM may serve to maintain incoming contextual information while retrieving the necessary lexical and syntactic information from long-term memory. Because of the limited capacity of WM, it may constrain the amount of information an individual is able to process at any given moment.

Similar to the findings in adults with foreign language learning, STM and WM in children have been related to aspects of native language comprehension. These positive correlations have been found between verbal STM or verbal WM and vocabulary acquisition, vocabulary comprehension (e.g., Gathercole & Baddeley, 1989), acquisition of grammatical forms, comprehension of grammatical forms in typical and atypical populations (e.g., Ellis & Sinclair, 1996; Robinson, Mervis, & Robinson, 2003), and sentence comprehension (Daneman & Merikle, 1996). Research has suggested that STM may play an important role in the acquisition of vocabulary during the process of committing words to long-term memory (Gathercole, Hitch, Service, & Martin, 1997). Children with an increased STM capacity should have better defined short-term phonological representations of words than children with lesser capacity, increasing the likelihood that the representation will be committed to long-term memory (Gathercole & Baddeley, 1990).

The way in which STM memory influences phonological representations relies on the nature of the temporary representation. The temporary representation of incoming auditory information is represented by a memory trace, or the temporary activation of a network in the long-term memory system (see Baddeley, Gathercole, & Papagno, 1998 for a further explanation). When children are learning new words, a complete network representing the particular auditory information does not yet exist. Partial networks, or small parts of existing networks from familiar long-term representations are activated. As children are learning new words, these activations eventually form a new network that the child will activate the next time the word is heard (Bates & Elman, 2000). In order to form a new network, variants of the incoming phonological representations are consolidated into a holistic representation. The quality of the short-term representation, therefore, will influence the formation of this holistic representation by shaping how stored phonological representations are combined to form a word (Baddeley et al., 1998). Repeated exposure to a short-term variant of the long-term representation, can therefore, alter the nature of the stored representation.

The child with increased STM capacity should have better short-term representations, therefore, because the temporary representation is a more complete and more accurate representation. Through repeated exposure to the speech stream, a child with increased STM capacity should be able to more completely represent a particular word and will then learn the word more quickly than a child with lesser capacity. It is assumed that the child with lesser STM capacity will not be able to represent the word in a complete manner or will represent slight variations of the word. These discrepancies will cause the child to take longer to learn the word because the long term learning of the word depends on frequent representations of the word.

STM and WM may be related to children's acquisition of grammatical forms in a similar way as they are to vocabulary acquisition (Adams & Gathercole, 2000). Those children with a greater STM and WM capacity may be able to represent a grammatical structure more consistently than children with a lesser memory capacity and thus increase the likelihood that the structure is committed to long-term memory. In children, who are still acquiring vocabulary and grammatical structures, the process of understanding incoming words and sentences may be more difficult than the relatively automatic process that occurs in adults during the same task. Because of this difficulty, children may rely more heavily on aspects of verbal memory, particularly working memory, to process and to understand incoming information (Adams & Gathercole, 1995).

In contrast to research conducted on language comprehension, very little research has examined the role of STM and WM in language production. STM and WM have been shown to be related to receptive vocabulary and grammar knowledge, and given the known links between receptive and expressive language (Bates & Goodman, 1997), aspects of verbal memory also may play a role in language production. The few existing studies, which focus on production in children, reveal significant positive correlations with aspects of verbal STM (Adams & Gathercole, 1995; 1996, Blake et al., 1994; Gathercole, Hitch, Service, & Martin, 1997). Existing research has examined only whether STM has direct influences on language production. The relationship between aspects of verbal memory and language production, however, may be mediated by the child's existing lexical and grammatical representations. The exact nature of the relationship between STM and productive language, therefore, remains unclear. The constraints associated with STM and WM may limit a child's ability to retrieve verbal information effectively, thus limiting their language production. The possibility exists that this relationship is either partially or fully mediated.

Theoretical Path Models of Speech Production

Theories of speech production suggest that a speech output buffer may play an important role in the production of utterances (e.g., Shallice, Rumiati, & Zadini, 2000). The speech output buffer is a hypothesized construct that functions to combine and to consolidate information prior to speech production. The information processed in the speech output buffer may include basic syntactic frames, parts of speech, or word combinations (Speidel, 1993). Debate exists as to whether a speech output buffer is necessary in adults during language production. Instead of relying on an area to plan and retain parts of utterances, adults may produce output by activating phonological representations stored in long-term memory directly (see Adams & Gathercole, 1995). Preschool aged children, however, who may need to construct word combinations and grammatical constructions actively to produce utterances, may rely on such a space.

Most theories of speech production (see Adams & Gathercole, 1996 for a review) suggest that lexical access occurs in two steps. In the first step, the semantic-syntactic nature of the word is accessed whereas in the second, the phonological form of the word is accessed from long-term memory. For children with limited verbal memory capacity, long-term representations may not be accessed efficiently (Gathercole et al., 1997). STM and WM may both serve as part of the speech output buffer in children by holding syntactic phrases while the correct lexical or phonological form is found to produce an utterance (Martin & Freedman, 2001). In this role, STM and WM may constrain the amount of information that can be held in the speech output buffer and thus may limit the length and complexity of the utterance directly. If this is the case, a child will only be able to produce long, complex utterances if the necessary lexical and syntactic information is accessed easily, or if the child is able to access that information quickly.

Rapid access depends on the efficiency of the memory system. As reviewed, more efficient STM skills result in better phonological representations, which should be easier to retrieve. Existing research has revealed correlations between verbal STM and language production, yet has failed to explicitly examine the role of receptive language in this relationship (e.g., Adams & Gathercole, 1996)

Two models of speech production address the possible role of receptive language in the relationship between memory and language production (Adams & Gathercole, 2000; Bock, 1982; Chapman, Seung, Schwartz, & Raining-Bird, 2000). The first model suggests that the relationship between WM (including STM) and speech production is fully mediated by receptive language. In this model, verbal WM directly influences receptive language, which then influences speech production. Those individuals with a greater verbal WM capacity should have greater receptive language skills because they will be able to acquire long-term vocabulary and grammatical representations more efficiently than individuals with lower capacity (Adams & Gathercole, 2000). Additionally, the individuals with greater WM capacity should retain more vocabulary and grammatical structures than individuals with lesser WM capacity (Speidel, 1993). This increased receptive language will then influence speech production. Instead of utilizing resources to establish an appropriate syntactic phrase with the correct terms, individuals with greater receptive language should be able to recall the terms and structure easier and more automatically than individuals with lower WM capacity and receptive language.

A second model of speech production suggests that the relationship between verbal WM and speech production may be only partially mediated by receptive language. If the relationship is partially mediated, then verbal WM should continue to influence language production directly, even after accounting for the effects of receptive language. A partially mediated model suggests that an individual's extant lexical and syntactic knowledge is not the only factor necessary to produce speech, and that WM still plays an important role. According to a partially mediated model of speech production, the ability to construct an utterance efficiently requires more than vocabulary or grammatical knowledge. Additional resources are necessary to locate the correct syntactic structure and lexical terms to convey the intended meaning. Finding a partially mediated model would lend support to the idea that verbal WM influences the speech output buffer in children's language production.

In the following sections, I will examine more closely the literature on the relationship between aspects of verbal STM and WM and receptive language development, including vocabulary and grammar comprehension. This will be followed by a review of the literature on the relationship between verbal STM and WM and productive vocabulary and grammar. Before reviewing this literature, however, a very brief presentation of the types of tasks used to measure STM and WM is necessary.

Digit span, word span, or nonword repetition tasks frequently are used to measure verbal STM capacity in children and adults. In these tasks, individuals hear a list of digits, words, or nonwords and then are required to recall the list in sequence verbally. These tasks use the maximum number of items recalled as a measure of verbal STM capacity. The nonword repetition task is designed to minimize the influence of lexical knowledge present in digit or word span tasks and uses either the number of nonwords or syllables correctly recalled as a measure of STM capacity. WM tasks include a processing component in addition to simple recall. Backward digit span is an example of a WM task in which individuals are required to reverse the order of a list of digits during recall. The maximum number of digits correctly recalled is used as a measure of verbal WM capacity. Other WM measures involve tasks such as recalling the last word of each sentence after hearing a block of sentences (Daneman & Carpenter, 1980). In this task, the number of final words the individual correctly recalls measures WM capacity.

Memory and Receptive Language

Verbal Short-Term Memory and Receptive Vocabulary Development

Early research examining the relationship between aspects of verbal STM and vocabulary (Atkins & Baddeley, 1998; Baddeley, Papgno, & Vallar, 1988; Gathercole, Service, Hitch, Adams, & Martin, 1999; Service, 1992) suggested that STM plays an important role in the comprehension as well as the acquisition of vocabulary. Initial research found that children displaying disordered or delayed language development, such as low levels of vocabulary for their age, were dramatically impaired on measures of verbal STM when compared to children with typical language development (e.g., Gathercole & Baddeley, 1990). Additional studies were conducted, examining both adults and children, and found that factors that impair verbal STM performance (e.g., phonological similarity, word length, suppression of rehearsal) also impair word learning in foreign languages (Gathercole et. al., 1999). The authors of these studies suggested that due to the similarity in impaired performance, the two constructs may be related such that memory capacity may aid language learning. Further research was conducted that found a relationship between verbal STM capacity and vocabulary level in native language learning, but only for children (Baddeley, Gathercole, & Papagno, 1998; Gathercole & Baddeley, 1989; Gathercole, Willis, Emslie, & Baddeley, 1992). Examining the relationship between receptive vocabulary levels and STM capacity measured by digit span and nonword repetition tasks, correlations between children's vocabulary and concurrent measures of STM ranged from .22 to .46 (see Baddeley et al., 1998 for a review).

In an attempt to examine the direction of causality among the observed correlations, studies were conducted with children between the ages of three- and eight-years old, examining the role of verbal STM in receptive vocabulary development. An initial study examining the role of verbal STM on natural vocabulary acquisition in young children found a correlation between verbal STM skills and receptive vocabulary scores measured one year later (Gathercole & Baddeley, 1989). In this study, after controlling for receptive vocabulary level at age four, STM capacity at age four was correlated with receptive vocabulary level at age five. A subsequent study (Gathercole et al., 1992) applied cross-lag correlation techniques on large samples of four- through eight-year-old children to clarify the nature of the relationship found by Gathercole and Baddeley (1989). In this study, partial correlations controlling for age were computed between STM scores and receptive vocabulary scores. The partial correlation between STM at age four and vocabulary at age five was significantly greater than the converse partial correlation between vocabulary at age four and STM at age five. The authors suggest that the significant difference between these two paths indicates that STM plays a stronger causal role in vocabulary development rather than the opposing relationship. This path between STM memory at age four and vocabulary at age five remained significant, even after accounting for vocabulary knowledge at age four.

The authors of this study (Gathercole et al., 1992) did not find evidence of a causal relationship between STM and vocabulary for subsequent age intervals. After age five, the relationship between verbal STM and vocabulary acquisition begins to shift, with STM constraints playing an increasingly smaller role in vocabulary acquisition (Gathercole et al., 1992). One possible reason for the relationship changing may be because the process of acquisition becomes more automatic, thus reducing the reliance on STM (Gathercole & Baddeley, 1989). Furthermore, in older children other vocabulary acquisition methods, such as reading, may begin to influence vocabulary growth to a greater degree than STM constraints (Gathercole et al., 1992).

Collectively, the reviewed studies suggest that aspects of verbal STM are important to the acquisition of vocabulary in children under the age of five. In children, the initial stages in the process of learning a new word involve creating phonological representations of an unfamiliar word (Gathercole & Baddeley, 1989). These phonological representations are maintained in verbal STM. Verbal STM may be necessary to rehearse the phonological representations of the new word until it is committed to long-term memory.

Verbal Short-term Memory, Verbal Working Memory, and Receptive Grammar

Although early theorists believed vocabulary and grammar were relatively independent, current research does not support this idea (Bates & Goodman, 1997). Research has demonstrated a close relationship between lexical and grammatical knowledge in young children showing current as well as previous vocabulary levels correlating very highly with grammatical production (see Bates & Goodman, 1997). As lexical knowledge increases, syntactic knowledge also increases in an almost identical trajectory. Examining children's grammatical complexity based on their vocabulary size reveals that as vocabulary increases, complexity also increases. Though this relationship is not linear at smaller vocabulary levels, it becomes increasingly linear with larger vocabulary levels (Bates & Goodman, 1997). Because of the corresponding patterns of development, similar mechanisms may underpin lexical and grammatical acquisition. Though limited research exists examining correlations between verbal STM and WM and grammatical knowledge, there is support for the idea that lexical and grammatical acquisition develop under similar processing constraints (Ellis & Sinclair, 1996).

As in vocabulary acquisition, studies examining grammatical ability and verbal STM in foreign languages find a relationship between verbal STM capacity and the acquisition of syntactical rules (Gathercole et al., 1999; Service, 1992). Those individuals with greater verbal STM capacity are able to learn the rules of a new language at a faster rate than the individuals with lower memory capacity (Gathercole et al., 1999). This relationship between verbal STM and grammar acquisition has been found in both adults and children learning foreign languages (Gathercole et al., 1999; Service, 1992).

In studies examining native language learning, a relationship between verbal WM capacity and grammatical comprehension is also found (see Ellis & Sinclair, 1996). By assessing a child's ability to comprehend increasingly complex grammatical structures, grammar comprehension has been positively correlated with verbal WM capacity in normally developing as well as atypical populations of children (e.g., Baddeley & Wilson, 1993; Ellis & Sinclair, 1996; Gordon, Hendrick, & Levine, 2002; Mann, Cowin, & Schoenheimer, 1989; Robinson et al., 2003). Examining the effects of verbal WM on grammatical comprehension in typically developing children and children with Williams Syndrome, Robinson and colleagues (2003) found verbal WM measures were related to grammatical comprehension in both groups of children. That is, children with greater verbal WM capacity were able to understand sentences of greater complexity than the children with lower verbal WM capacity. A similar pattern of results was found when examining children with reading disabilities (Mann et al., 1989). Those readers with greater WM capacity were able to comprehend more syntactically complex sentences than those readers with poor WM capacity. These studies suggest that the relationship between verbal WM and grammatical comprehension is robust. In children with varying levels of linguistic ability, the capability to hold and manipulate information supports the comprehension of increasingly complicated syntactic structures.

A relationship between verbal WM and grammatical comprehension, as well as a relationship between verbal STM and grammatical comprehension has also been found with typically developing children (Adams, Bourke, & Willis, 1999). Using a verbal WM measure adapted from Daneman and Caprenter's (1980) reading and listening span tasks, Adams and colleagues (1999) examined the contribution of WM and STM on children's comprehension of spoken language. The results of their study suggested that for 4- and 5-year-old children, verbal WM, as well as STM, are related independently and significantly to vocabulary and language (syntactic) comprehension. Children who were better at verbal WM tasks also were significantly more proficient grammatically and had significantly larger receptive vocabularies than children who performed poorly on verbal WM tasks (Adams et al., 1999).

Memory and Language Production

Studies examining the relationship between verbal STM and language production have been limited in number. Early research with adults found no relationship between measures of verbal STM and speech production. In the language production of adults, factors such as articulatory suppression and word length that are known to interfere with the processing of verbal information do not affect sentence production (Adams & Gathercole, 1995). Further, in patients with acquired neuropsychological damage affecting STM, language production is relatively unaffected (Martin, 1987). These findings suggest that verbal STM does not play a significant role in adult speech production.

The lack of a relationship between STM and production may be explained by the way in which adults use language (see Adams & Gathercole, 1995). In adults, language production is relatively automatic, placing little demand on limited memory resources. In most circumstances, adult speakers do not need to rely on their verbal WM to compose fluent sentences. The process of language production in children, however, is very different than the process in adults. Language production in children is much slower and more effortful when compared to the automatic process that occurs in adult speakers (Adams & Gathercole, 1995). In children, this controlled and effortful processing taxes limited resources as is exemplified in telegraphic speech. Telegraphic speech, in which children simplify speech by omitting function words, may be the result of children's reduced verbal WM capacity in comparison to adults (see Blake et al., 1994). Further examples of the competition of resources in children's speech are visible in tradeoffs between lexical availability and fluent utterances, phonological complexity and the complexity of utterances, and between phonological accuracy and greater semantic complexity

(Adams & Gathercole, 1996). Because of the limited capacity of children's verbal STM and WM, the subsequent constraints on language production skills should be greater than in adults who possess greater verbal memory capacity (Willis & Gathercole, 2001).

Verbal Short-term Memory and Expressive Vocabulary

Whereas many studies have examined the relationship between measures of verbal STM and receptive vocabulary, only two studies have examined the relationship between verbal STM and expressive vocabulary in children (i.e., Adams & Gathercole, 1995; Gathercole, Hitch, Service, & Martin, 1997). In the first such study, five-year-old children's expressive vocabulary scores on both the Expressive One-Word Picture Vocabulary Scale (Gardner, 1990) and the Oral Vocabulary component of the Word Knowledge test in the McCarthy Scales of Children's Abilities (McCarthy, 1970) were found to correlate significantly with verbal STM capacity after controlling for age (Gathercole et al., 1997). Those children who performed better on the STM measures exhibited higher scores on expressive vocabulary task than the children who performed more poorly on the memory measures. The second study examining expressive vocabulary and STM capacity in three-year-old children reported that children with greater STM capacity produced a wider variety of words during free speech samples when compared with children with lesser capacity (Adams & Gathercole, 1995). Both studies suggest a link exists between aspects of verbal STM and expressive vocabulary, yet neither study examined the influence of receptive vocabulary.

Verbal Short-term Memory, Working Memory, and Grammar Production

Similar to the lack of research with expressive vocabulary, little research exists examining grammar production and STM and WM. To date, only three studies have examined the relationship between children's grammar production and verbal STM (Adams & Gathercole, 1995, 1996; Blake et. al, 1994). The first of these studies (Blake et al., 1994) examined the role of verbal STM, measured by word span, in children's spontaneous speech samples. The study found that word span significantly predicted mean length utterance (MLU) of spontaneous speech samples for 2- and 3-year old children better than either chronological age or mental age. These findings, however, did not hold for the 4- and 5-year-old children in the sample. Because the word span task uses real words as stimulus items, performance may be confounded by a child's lexical knowledge. Children who perform better on a word span task may be doing so only because of their increased knowledge or familiarity of the words used in the task. The confounded relationship makes it impossible to separate the effects of receptive language from the effects of verbal STM when using a word span task to predict grammar production. Additionally, the inability to separate the effects of receptive vocabulary and STM makes it difficult to differentiate between models of speech production.

The remaining two studies that examined grammar production and STM were both part of a longitudinal study conducted by Gathercole and Adams examining verbal STM skills in very young children (see Gathercole and Adams, 1993). The sample in the longitudinal study consisted of 111 children aged two and three at the start of the study. The first publication from the study (Adams & Gathercole, 1995) examined a subsample of 38 three-year-old children. This study improved on the Blake et al. (1994) methodology by adding a nonword repetition task as a measure of verbal STM. In this study, 3-year-old children were grouped according to their verbal STM abilities (i.e., high and low verbal memory). The verbal memory groups were formed based on children's combined performance on the nonword repetition task and a digit span task. The nineteen children with the highest and the nineteen children with the lowest average verbal memory scores were chosen for the groups. Although the performance on the measures of verbal STM overlapped to a degree, groups were significantly different in terms of verbal memory. Productive grammar, the outcome measure, was measured using speech samples from free play sessions. Both Index of Productive Syntax (Scarborough, 1990) scores and MLU in morphemes were calculated from the speech samples and used as separate indices of productive grammar. The results of the study revealed that those children with better verbal memory skills produced longer utterances that were more grammatically complex than the utterances of the children in the low verbal memory group. As in the Blake et al. (1994) study, however, the role of receptive language was not controlled for thereby offering little support to either model of speech production.

In their second published study examining verbal STM and grammar production, Adams and Gathercole (1996) observed the children that had continued in the longitudinal study. This sample consisted of 89 four- and five- year-old children that remained from the original 111 children at the start of the study. The five-year old children in this sample were the same group of children used in the previous Adams and Gathercole (1995) study. In this study, Adams and Gathercole (1996) further improved the previous methodology by including measures of expressive and receptive vocabulary. Grammar production was measured by the mean length of the five longest utterances (MLU) produced by children on the Bus Story. The Bus story requires children to recreate a story using pictorial cues. In the study, verbal STM was measured by nonword repetition, memory span (including both word and digit span), and articulation rate. Unlike Blake et al. (1994) who found no relationship between STM and grammar production in four- and five-year-old children, this study found a significant correlation between STM and grammar production, even after controlling for both expressive and receptive vocabulary levels. The results of this study indicated that only nonword repetition accounted for a significant amount of unique variance in MLU after controlling for vocabulary knowledge, supporting a partially mediated model of speech production.

Blake et al. (1994) was the first to suggest the link between STM and grammar production, although the role of receptive language in the relation was not clear. Whereas both Adams and Gathercole (1995, 1996) studies also suggest that verbal STM is related to grammar production, these studies also are not conclusive with respect to the role of receptive language in production. Interestingly, children in the initial study (1995) did not differ in their receptive vocabulary scores although they were separated into high and low verbal memory groups. This finding is contradictory to the many studies that find a significant relationship between verbal memory capacity and receptive vocabulary (see Baddeley et al., 1998 for a review). These studies suggest that children with greater verbal memory capacity have higher receptive vocabulary scores than the children with lesser verbal memory capacity (e.g., Ellis & Sinclair, 1996; Gathercole & Adams, 1993; Gathercole et al., 1997). Additionally, in the 1995 study, children's receptive language scores did not correlate significantly with any of the production measures. This lack of correlation is incongruous with existing literature, which finds strong correlations between receptive and expressive language (e.g., Gathercole et al., 1997). Moreover, receptive language in the initial study (Adams & Gathercole, 1995) was not explicitly controlled for and thus may still have influenced the relationship between STM and grammar production. Those children with greater receptive vocabulary scores may have an advantage when producing utterances simply due to their greater lexical base. Without the ability to account for the contribution of receptive language, it is difficult to offer support to either model of speech production.

Although the findings of the second Adams and Gathercole study (1996) lend stronger support to the existence of a partially mediated model of speech production by showing the continued influence of STM on production after vocabulary knowledge is taken into account, the role of receptive language remains unclear. Vocabulary scores were found to predict a large proportion of the variance (27%) in the grammar production of four- and five-year olds. After controlling for vocabulary, aspects of verbal STM accounted for a significant, but smaller (3.5%), amount of unique variance. Vocabulary scores, however, included the combination of receptive and expressive language scores. In doing this, Adams and Gathercole (1996) did not separate the unique contribution receptive vocabulary may have on grammar production. By including expressive vocabulary as a predictor of productive grammar, Adams and Gathercole may have masked the potential influence of verbal STM on production. The findings of this study are limited to suggesting that vocabulary knowledge, some combination of receptive and expressive, is related to differences in grammar production.

A further discussion is necessary regarding the measure of grammar production used in Adams and Gathercole's second (1996) study. Productive grammar was assessed from the five longest utterances taken from the Bus Story. In this task, after hearing a story told by the experimenter, children are asked to retell a story using only pictures as cues. Measuring grammar production in this way does not depict a natural sample of the child's ability. The children's grammatical complexity may be influenced by the complexity present in the experimenter's telling of the story. Further, although performance on the Bus Story correlates with MLU (see Adams & Gathercole, 1996), measuring grammar production from the five longest utterances estimates the maximum level of grammatical complexity a child is able to produce. This may overestimate the role of receptive language in typical grammar production because the child may rely primarily on only the best-learned grammatical structures rather than verbal STM and WM to produce a wider array of spontaneous utterances. Utilizing a spontaneous speech sample to assess grammar production may be more likely to include utterances in which the child must rely on WM to a greater extent to compose the appropriate syntactical frame.

Measures of Verbal Short-Term and Verbal Working Memory

The studies reviewed thus far utilized a digit span task, a word span task, and/or a nonword repetition task as measures of STM capacity. As previously suggested, performance on digit span or word span tasks rely, to some extent, on extant lexical knowledge because real words are used as stimulus items. Therefore individuals with similar STM capacity may perform differently based on their receptive language skills.

Gathercole and colleagues (1997) suggest that nonword repetition tasks offer a more pure measure of verbal STM because they decrease the influence of lexical knowledge. In the nonword repetition task, individuals are required to repeat back a list of nonsense words. The Children's Test of Nonword Repetition (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994) contains a list of nonwords which follow the phonotactic structure of the English language. This task was used in many of the studies discussed that measured STM with a nonword repetition task. Research by Gathercole and colleagues (1991), however, found that the 'wordlikeness' of nonwords in this task interacts with performance on nonword repetition tasks, suggesting that nonword performance is not necessarily independent of specific or general linguistic skill (Gathercole, Willis, Emslie, & Baddeley, 1991). In nonword repetition tasks, wordlike nonwords contain phonetic representations that are common to the language (e.g., tull and brastering are more wordlike nonwords than teɪvak and naɪtʃouveɪb). Many of the nonwords used in the CNRep contain syllable combinations that are found frequently in common English words. These familiar syllables potentially activate real world syllables stored in long-term memory and confound performance. The lexical knowledge that the task was designed to avoid, therefore, continues to influence performance (Dollaghan, Biber, & Campbell, 1993).

In an attempt to separate the lexical influences from nonword repetition tasks, Dollaghan and Campbell (1998) developed a list of nonwords designed to minimize the effects of prior linguistic knowledge. The nonwords devised for this task, Dolloghan's Nonword Repetition Task (DNWRT), continue to follow phonotactic structures of the English language (as in the CNRep). To ensure that the nonwords do not rely on linguistic knowledge, individual phoneme combinations that appear frequently in English words were not included in any nonwords. Additionally, phonemes in the nonwords were assigned only to positions in which they occur less that 25% of the time in the English language. Studies utilizing DNWRT find strong predictability of language status. That is, contrary to findings based on other nonword repetition tasks, performance on DNWRT accurately identifies children diagnosed by a speech language pathologist as having a language impairment from those children with typically developing language (Dollaghan & Campbell, 1998). Although DNWRT has been used in place of other nonword repetition tasks to assess language status, the role of DNWRT as a measure of STM, has not been investigated in relation to children's typical language production.

The cited studies examining the relationship between language production and STM (Adams & Gathercole, 1995, 1996; Blake et al., 1994) did not include processing components assessed by measures of verbal WM. The backward digit span task has been used to assess verbal WM in the relationship with comprehension in adults (e.g., Norman et al., 1992) and children (e.g., Robinson et al., 2003) and may also be related to language production. Although this task uses real words as stimulus items, the backward digit span task requires individuals to verbally recall a list of digits in backwards order. This task is considered a WM task, especially in children, because of the processing demands required by manipulating the sequence of items (Hutton & Towse, 2001). Manipulation of order is considered to be automatic in adults, and thus digit span backwards is frequently used as a measure of STM. In children, however, altering the order of a list is not automatic and taxes a child's memory resources. Further, in children, factor analyses reveal backward digit span to load with other WM tasks as opposed to STM tasks (Hutton & Towse, 2000). For these reasons, backward digit span is considered to be a working memory task in children.

Because English is a language highly dependent on word order (Chomsky, 1965), this ability to manipulate the order of information is crucial in language production and comprehension. For example, to comprehend the sentence, '*The ball that was blue is next to the chair that is red,'* an individual, in part, must be able to map the color blue onto the ball and the color red onto the chair, even though the referent of the modifier actually precedes the modifier itself. To do this successfully, a child must temporarily hold representations of the words while applying the correct meaning and order to abstract the meaning of the sentence. Further, language comprehension and production require an individual to simultaneously process many pieces of information. To comprehend an utterance, for example, an individual must be able to parse, to encode, and to temporarily store phonetic units as well as switch between contextual cues and long-term lexical memories (Robinson et al., 2003).

Purpose and Hypotheses of the Study

The reviewed literature suggests that a link exists between verbal STM and receptive vocabulary (e.g., Baddeley et al., 1998) and between verbal STM and WM and receptive grammar (e.g., Adams et al., 1999). Further, a limited number of studies suggest that a relationship exists between STM and expressive vocabulary and STM and grammar (e.g., Adams & Gathercole, 1996). The present study will attempt to replicate these findings between STM and productive language. Further, in order to clarify these relationships between verbal STM and productive language the proposed study will test the potentially mediating role of receptive language in the relation between verbal STM and WM and productive language.

It was hypothesized that the measures of STM memory would be significantly related to receptive vocabulary and both STM and WM would be significantly correlated with receptive grammar. Further it was hypothesized that the measures of STM and WM would be significantly related to expressive vocabulary and productive grammar. The relationship between receptive language and expressive language also was hypothesized to be significant. It was unclear, however, whether the models of speech production would be fully or partially mediated.

Method

Participants

Forty children representing the ages of three-, four-, and five-years-old participated in the study, resulting in 120 children total. The children were all between the ages of 3;0 and 5;11. All participants in the current study were recruited as part of larger study examining language and memory in preschool age children. Participants in the study were recruited from metro Atlanta area preschools, daycare centers, and private elementary schools. The sample consisted of 51.6% males and 48.3% females. Of the current sample, 27% were African American, 66% were White, and 3% were Asian, and 4% were of mixed racial background.

Materials

A battery of fourteen tasks was administered in randomized order to each child as part of a larger ongoing study. The battery consisted of standardized language measures, standardized and experimental verbal- and visual- memory measures, and three free-play sessions. For the purposes of the current study, only the language and verbal memory measures were examined. These measures and free-play sessions are described below.

Receptive language is comprised of receptive vocabulary and receptive grammar. Receptive vocabulary was measured using the Peabody Picture Vocabulary Test (PPVT) whereas receptive grammar was assessed using the Test for Reception of Grammar (TROG). Expressive vocabulary was measured using the Peabody Expressive Vocabulary Test (EVT) and productive grammar, obtained from the transcripts, was measured by mean length utterance in morphemes (MLUm scores) and Index of Productive Syntax (IPSyn) scores.

Peabody Picture Vocabulary Test – Third Edition (PPVT-3; Dunn & Dunn, 1997). The PPVT-3 is a standardized measure of receptive vocabulary for Standard American English and is used commonly for children over the age of 2½ and is appropriate up to the age of 90. During testing, the administrator read a stimulus word while showing the participant a choice of four illustrations. The participant was required to point to the illustration that matched the stimulus word. The test takes approximately 15 to 20 minutes to administer. Age-based standard scores as well as percentile ranks are provided for the PPVT-3. For form III A, which was used in the current study, the test manual reports internal consistency coefficients as corrected split-half reliabilities that ranged from .89 to .97 (median = .94). The test-retest reliability corrected coefficients for ages 2.6- 5.11 is reported as .92 (Time 1: mean = 106.1, SD = 12.4, Time 2: mean = 107.9, SD = 14.0).

Peabody Expressive Vocabulary Test (EVT; Williams, 1997). The EVT is a standardized measure of expressive vocabulary for Standard American English and commonly is used for children over the age of 2 ½ and is appropriate up to the age of 90. The format of the test is similar to that of the PPVT-3. In this test, the administrator showed the child a picture, provided the name of the picture, and asked the child to respond verbally with an alternative label for the picture. For children under the age of 5, testing began with children verbally labeling items. For those children at least 5-years-old, testing began with synonym items. This test takes approximately 15 to 20 minutes to administer and provides age-based standard scores and percentile ranks. The test manual reports internal consistency coefficients as corrected split-half reliabilities that range from .85to .97 (median = .91). The test-retest reliability corrected coefficients for ages 2.6- 5.11 is reported as .77 (Time 1: mean = 103.1, SD = 14.5, Time 2: mean = 106.0, SD = 14.4).

Test for Reception of Grammar (TROG; Bishop, 1989). The TROG is a standardized measure designed to assess the understanding of grammatical contrasts in English. The TROG provides standardized scores for children between the ages of 4 and 12 years old. This task has been used with younger children and atypical populations and demonstrates variability in these samples suggesting it is appropriate for younger children. In this task, the administrator read a word or phrase and the participant chose the correct picture illustrating the word or phrase. The participant was given four pictures to choose from including lexical and grammatical foils. These foils were included in an attempt to reveal the participant's error pattern and determine whether the errors were due to difficulty with grammatical structures or to a more generalized problem such as inattention. The task began with the administrator providing vocabulary words for the child to identify and continued to phrases that increase in grammatical complexity with each trial. The TROG takes approximately 15 minutes to administer and provides both age-based standard scores and percentile ranks. Internal consistency correlations, reported as split-half reliabilities are .76 for ages 6.0 - 6.11 and .65 for ages 8.0 - 8.11. Alpha is reported as .77.

Free-play sessions. Each child participated in three short free-play sessions lasting from 5 to 10 minutes each. Each play session focused on either finger puppets or a farm set as props. At least once during each testing session, the test administrator requested a break to play with the puppets or farm set, thus making the order of the play sessions quasi-randomized. The administrator randomly chose either the farm or puppet props for the first play session, and the remaining props were used in the second play session. For the third play session, the child chose the props of his or her choice (i.e., either the finger puppets or farm set). For all free-play sessions, the child and administrator played together with the props with the administrator attempting to engage the child in conversation. No script was provided for the free play sessions, rather the administrator was trained to interact in a way that encourages conversation by the child. The free play sessions were recorded digitally using a MP3 recorder and later transcribed. The transcriptions of the free play sessions provided the productive grammar variables in the current study.

Transcripts. Transcriptions of the free play sessions were generated from the digitally recorded free play sessions. Systematic Analysis of Language Transcripts (SALT, Miller & Chapman, 1983) conventions were used as guidelines during the transcription process (also see Chapman, 1981). Graduate students and research assistants transcribed the three free play sessions for each participant. One transcriber completed a transcript for each participant. A second transcriber independently reviewed the transcript while listening to the free play session and noted any disagreements. Disagreements then were discussed until consensus between the two transcribers was reached. Each transcript was entered and analyzed using SALT. SALT analyses were also conducted after removing all children's self repetitions, imitations, and answers to questions in each transcript. For the purposes of the current study, mean length utterance in morphemes (MLUm), provided by SALT, provided one outcome measure for productive grammar. Mean length utterance was calculated by using the conventional guidelines for counting morphemes (Brown, 1973) and provides the average number of morphemes per utterance for each participant. Internal consistency, reported as split-half correlations, ranges between .92 to .97 for 100 utterance samples for children between 2- and 6-years-old (Eisenberg, Fersko, & Lundgren, 2001).

Transcripts also were analyzed using the Index of Productive Syntax (IPSyn; Scarborough, 1990). Only complete and intelligible child utterances that were not exact imitations of adult utterances were entered into IPSyn for analysis, as per Scarborough (1990).

Self-repetitions and answers to questions were also excluded from analysis. For each child, three lists of 100 random child utterances from the three play sessions were entered into IPSyn for analysis. IPSyn provides an estimate of developing grammatical complexity by identifying fundamental grammatical forms in the child's speech. Four different grammatical types classify these grammatical forms: noun phrases, verb phrases, question/negation constructions, and sentence structure. Items included in each subscale are given in Appendix A. Because IPSyn measures developing grammatical forms, not mastery of these forms, each item was given a score of 0,1, or 2, for each appearance. Thus, up to two instances of each grammatical form was credited. Children obtained scores for each subscale, which were summed to provide a total score. This total score provided the second outcome measure for productive grammar. Subscale scores, however, are available for more fine-grained exploratory analyses. The internal consistency coefficients reported as split half reliability IPSyn scores from two successive 100-utterance corpora is .986 (Scarborough, 1990).

Children were administered a total eight short-term memory and working memory measures. In the current study only the verbal memory subset of the measures were analyzed. These measures are described in detail below. Forward span and Dollaghan's Nonword Repetition Task (DNWRT) were used to assess STM and backward span was used to measure WM.

Forward Span (Wechsler, 1982). The forward span is a commonly used measure for children and adults to assess verbal STM capacity. In this task, the experimenter read a list of digits aloud. The participant was required to verbally repeat the digits in order of presentation. The number of digits in each list increased from two to seven in each list presentation. Each list presentation contained two lists of that particular length. The task was stopped when a child incorrectly recalled both lists in a list presentation. This task took approximately 7 minutes to administer. The forward span is a measure of storage because the participant must temporarily hold information prior to repeating it. Internal consistency reported in the test manual as split-half reliability for forward and backward digit span ranges from .79 to .91 (mean = .85). The test-retest reliability corrected coefficient is reported as .67 (Time 1: mean = 10.0, SD = 2.7, Time 2: mean = 10.6, SD = 2.8).

Backward Span (Wechsler, 1982). Similar to the forward span, the backward span required participants to recall a list of numbers spoken by the experimenter. In this task, the participant verbally recalled the presented list in backward order. The number of digits in each list increased from two to seven in each list presentation. Each list presentation contained two lists of that particular length. The task ended when a child incorrectly recalled both lists in a list presentation. This task took approximately 7 minutes to administer. The backward span is a measure of verbal working memory because the participant must hold information, manipulate the order of that information, and then produce the manipulated information.

Dollaghan's Nonword Repetition Task (DNWRT; Dollaghan & Campbell, 1998). The DNWRT is a test of verbal memory designed to minimize the effects of prior lexical knowledge. As stated previously, to ensure that the nonwords did not rely on linguistic knowledge, individual phoneme combinations that appear frequently in English words were not included in any nonwords. Additionally, phonemes in the nonwords were assigned only to positions in which they occur less than 25% of the time in the English language. In this task, the experimenter played a computer file of a list of sixteen nonwords, which the child then repeated back to the experimenter. The number of syllables in the nonwords increased from one to four with four nonwords of each syllable length. The nonwords were designed to meet a number of constraints to ensure the task would be simple enough for young children to complete. The constraints on nonwords included beginning and ending with a consonant, the absence of consonant clusters, exclusion of the ‘late eight’ consonants, as well as exclusion of weak syllables and lax vowels (e.g., naɪb, voʊp, teɪvak). The DNWRT took approximately 8 minutes to administer. The DNWRT is a measure of storage because as in the forward span task, the participant must temporarily hold and then repeat information.

Scoring Procedures of Memory Measures. For the digit span tasks, participants' responses are typically scored in three different ways. *Trial* scores reflect the number of lists recalled correctly. *Span* scores calculated the longest length list the child correctly remembered and the *Item* scores reflect the total number of digits the child correctly recalled across the entire task. Item scores were calculated by counting the digits correct if they were the correct number in the correct location in the list. For children who recalled partial lists, the same criteria were used, with the correct location being the location of the stimulus list. These item scores, which calculate the total number of digits the child correctly recalled, were used analyses. Items scores were used because the span and trial scores do not differentiate between children who recall all lower levels correctly and those children who partially recall lower lists. That is, a child with a span score of three may have correctly recalled both lists at level two or only recalled one list at level two. In either case, the child would continue onto level three. There may be important differences between the children who are able to recall partial lists compared to children who recall full lists in the relation to productive grammar. Using item scores allows examination of these possible differences.

DNWRT can also scored in multiple ways. Nonwords were scored for number of syllables correct as well as total number of nonwords correct. Children's responses were scored as correct if the complete nonword was correctly repeated. Additions, in which children added any sounds or sound combinations to the nonword, were ignored and the response was counted as correct. The additions were not marked as incorrect because the child recalled the nonword representation completely, but also added on additional phonemes. The original representation was still present in the child's response. Variations in vowel sounds were also counted as correct. Consonant substitutions were scored following Shirberg's (1993) guidelines for age criteria for normal speech. These guidelines offer acceptable consonant substitutions for children between the ages of two and nine years of age. Appendix B includes a list of the nonwords used as well as the substitution rules for children between three- and five-years-old. A deletion of any sound in the nonword was counted as incorrect. Total number of nonwords calculated the number out of the sixteen possible nonwords that the child either recalled completely correctly, or recalled with any of the acceptable substitutions. Number of syllables was the total number of syllables out of a possible 40 that the child either recalled correctly or recalled with any of the acceptable substations. Number of syllables was used in analyses for reasons similar to those with digit span. Number of syllables allows differentiation of those children who recall partial nonwords from children who do not recall any of the nonword. Total number of nonwords recalled does not allow for this differentiation. Previous studies using the DNWRT (e.g., Dollaghan & Campbell, 1998) also use the number of syllables correct, however, percentage of syllables correct has been used as an alternative scoring method.

To summarize, although both digit span tasks and the nonword repetition task can be scored in multiple ways, in the current study, either item scores or syllable scores were used in analyses. These tasks can be scored in the alternate forms, however, if necessary.

Procedure

Preschools, daycare centers, and elementary schools were contacted by a member of the research lab and given a brief description of the research project. Information packets then were sent to the school or center containing detailed information regarding the study. After establishing interest by the school or daycare administrators, consent forms including a description of the study were given to the school or daycare to be sent home to parents. Parents indicated their desire to participate in the study by returning the consent form and cover letter. If parents did not respond to the primary request for consent, a second consent form was sent home. If parents did not respond to the second request, they were not contacted again.

Prior to testing, verbal assent was obtained from the child. The experimenter asked the child whether he or she wanted to play games and then described the tasks to the child. Trained graduate students and research assistants served as test administrators. The child was able withdraw from the study at any time if he or she desired. Parents were also able withdraw their child by contacting the principal investigator.

Children were tested in a quiet room in their school or daycare. The order of testing was randomized for each participant. The complete battery, including all available language and memory measures, took approximately two hours to administer. Testing was broken down into multiple sessions, each lasting approximately 45 minutes to 75 minutes. Session length was not specified, however, as many tests as possible were administered during each session. Testing continued as long as the child was not tired. Sessions for a participant did not occur on the same day, but all test sessions were completed within a week. Scoring of all measures was conducted by the administrator and then checked by a second trained experimenter. All scoring was completed following the published manual for each measure.

Results

Data Screening and Descriptive Analyses

Preliminary analyses involved data screening to identify outliers, missing data, or unusual distributions of scores or errors. The distributions of nonword repetition and IPSyn scores were negatively skewed (skewness = -1.10, SE = .222 and skewness = -.996, SE = .223, respectively). The distribution of digit span backward scores was positively skewed with a high number of children not being able to complete the task (skewness = .901, SE = 222). Skewed distributions were transformed prior to running analyses. Because of the large number of children who were not able to complete the digit span backwards task, transforming the distribution did not minimize the skew. After reflecting the variables, a series of transformations were conducted with the nonword repetition and IPSyn distributions; however, square root transformations resulted in the most normally distributed scores (skewness = .333, SE = .222 and skewness = .140, SE = .222, respectively). When applicable, analyses were conducted with the original skewed scores as well as the transformed scores and differences in findings are noted. All analyses were conducted using the Statistical Package for the Social Sciences (SPSS) 11.0.

Means and standard deviations of the measures used in the regression analyses are shown in Table 1. The mean standard scores for receptive vocabulary, receptive grammar, and expressive vocabulary in the current sample were all within normal range (Bishop, 1989; Dunn & Dunn, 1997; Williams, 1997). Although normed mean levels for MLUm are not available, Chapman (1981) offers guidelines for appropriate age and MLUm levels. These guidelines suggest that for children between 36 and 60 months, MLUm levels should range from 3.10 to 6.00. At 36 months, MLUm means should fall near 3.16 with a standard deviation of .69 and at

60 months, MLUm means should be near 5.63 with a standard deviation of 1.19. As can be seen from table 1, the range of MLUm in the current sample fell outside of the suggested range. The mean MLUm was lower than expected based on the guidelines whereas the standard deviation was closer to what would be expected for this age range. Normed guidelines were not available for the memory measures used in the current study. Short-term memory spans for this age range are typically measured as the longest span a child can retain as opposed to the total number of items that can be held, as reviewed previously. The STM scores in the current sample are comparable to those found in the literature using similar measures. In these studies (e.g., Adams & Gathercole, 1995; 1996) the mean number of digits children retain varies between 12 and 24. Although no norms were available for DNWRT scores in this age range, previous studies utilizing this task find preschool children retain a mean of 30 syllables. Working memory scores in the current study are similar to those found in the literature in which preschool age children retain between zero and three items.

Table 1

Means and Standard Deviations of Variables Used in Analyses

	M	SD	Range
Age in months	53.2	9.5	37-71
PPVT raw	65.81	23.69	13-123
PPVT standard	107.31	14.73	70-142
EVT raw	52.01	12.32	32-78
EVT standard	110.17	11.24	78-138
TROG raw	7.43	3.67	0-16
TROG standard$_a$	95.94	10.13	75-125
DNWRT syllables$_b$	29.29	6.82	8-39
Digit Span Forward-Items	16.34	7.87	0-41
Digit Span Backward-Items	3.99	4.61	0-18
MLUm	3.52	0.88	1.48-5.46
IPSyn	83.25	9.19	51-99
modified MLUm$_c$	4.16	0.9	1.38-6.03

a: TROG is not standardized for 3-year-olds; this includes only 4- and 5-year-old children

b: Out of a possilbe 40

c: Modified MLUm only used in exploratory analyses

Correlation Analyses

Correlations were computed among the variables to be included in the regression analyses. These correlations, including raw scores and standardized scores can be seen in Table 2. Partial correlations controlling for age are shown in Table 3. Original scores were used in the correlation analyses because transformation of the variables did not change this value except when transformed nonword repetition scores were used, as will be discussed further with the regression analyses. Experimenter error caused some of the administered tests to be unusable for up to five of the children in the study and because of this, the degrees of freedom may vary slightly in the cells of the correlation tables. The correlations reveal strong and significant relations among the measures of language as well as among the measures of memory. Though all memory measures significantly correlated with receptive vocabulary (ranging from .35 to .55) and receptive grammar (ranging from .38 to .60) before controlling for age, the correlation between receptive vocabulary and nonword repetition was no longer significant after controlling for age (see Table 3). The remaining memory measures continued to correlate significantly with receptive vocabulary and grammar after controlling for age (ranging from .21 to .34)

As can be seen from table 2, expressive vocabulary scores significantly correlated with all memory measures (ranging from .38 to .56). These correlations between expressive vocabulary and digit span forward, nonword repetition, and digit span backward remained significant after controlling for age. These correlations ranged between .19 and .28. Neither of the original productive grammar measures (i.e., MLUm or IPSyn scores), however, significantly correlated with any of the memory measures.

Table 2

Correlations Among Variables[a]

		DNWRT syllables	DigitSpan Forward	DigitSpan Backward	PPVT raw	PPVT standard	TROG raw	TROG standard	EVT raw	EVT standard	MLUm	IPSyn	modified MLUm
Memory Measures	DNWRT syllables	1											
	DigitSpan-Forward	.51***	1										
	DigitSpan-Backward	.38***	.54***	1									
Receptive Language	PPVT raw	.35***	.48***	.55***	1								
	PPVT standard	.26**	.31***	.32***	.88***	1							
	TROG raw	.38***	.49***	.60***	.76***	.60***	1						
	TROG standard[c]	.23*	.23*	.28*	.38***	.47***	.79***	1					
Expressive Language	EVT raw	.38***	.53***	.56***	.78***	.57***	.71***	.32**	1				
	EVT standard	.23*	.30***	.22*	.48***	.59***	.46***	.54***	.72***	1			
	MLUm	.09	.02	-.01	.35***	.43***	.21*	.29**	.23*	.32***	1		
	IPSyn	.05	.12	.07	.34***	.37***	.33***	.36***	.29**	.33***	.80***	1	
	modified MLUm[b]	.18*	.14	.05	.33***	.40***	.22*	.32**	.25**	.33***	.88***	.76***	1

A: *p < .05, **p < .01, ***p < .001

b: Modified MLUm was only used in exploratory analyses.

c: TROG is not standardized for 3-year-olds; this includes only 4- and 5-year-old children

Table 3

Partial Correlations Among Variables after Controlling for Age$_a$

		DNWRT syllables	DigitSpan Forward	DigitSpan Backward	PPVT raw	PPVT standard	TROG raw	TROG standard	EVT raw	EVT standard	MLUm	IPSyn	modified MLUm
Memory Measures	DNWRT syllables	1											
	DigitSpan-Forward	.23***	1										
	DigitSpan-Backward	.08*	.34***	1									
Receptive Language	PPVT raw	.17	.22*	.21*	1								
	PPVT standard	.18^{+}	.20*	.19*	.99***	1							
	TROG raw	.23*	.26**	.34***	.58***	.56***	1						
	TROG standard$_c$	.30**	.33**	.46***	.67***	.53***	1.0***	1					
Expressive Language	EVT raw	.20*	.28**	.19*	.56***	.55***	.47***	.61***	1				
	EVT standard	.22*	.30***	.22*	.59***	.59***	.52***	.55***	.97***	1			
	MLUm	.08	.01	-.05	.45***	.43***	.24**	.30**	.29***	.32***	1		
	IPSyn	.01	.08	.00	.37***	.34***	.34***	.38***	.31***	.32***	.80***	1	
	Modified MLUm$_b$	.18^{+}	.13	.03	.42***	.40***	.25**	.33**	.32***	.33***	.88***	.76***	1

a: $^{+}p < .10$, $*p < .05$, $**p < .01$, $***p < .001$

b: Modified MLUm was only used in exploratory analyses.

c: TROG is not standardized for 3-year-olds; this includes only 4- and 5-year-old children

Regression Analyses testing Models of Speech production

To test the mediation models, a series of regressions were conducted. Three initial relationships had to be established to examine the possibility of a mediating variable. These include significant correlations between the memory and productive language measures, between the memory and the receptive language measures, and between the receptive language and productive language measures. Only the variables that were significantly correlated after controlling for age were included when the models of speech production were tested. This resulted in two mediation models being tested. Raw scores were used in the regression analyses in order to compare scores of the standardized and unstandardized measures. Because raw scores were used, regression analyses controlled for age in the first step.

The measure of receptive grammar, TROG, is not standardized for children under the age of four. TROG raw scores were used in analyses so three-year-old children could be included. The variability of raw scores for 3-year-old children ($M = 4.75, SD = 2.72$) was slightly lower than that for the rest of the sample ($M = 8.76, SD = 3.34$; four- and five-year-olds only). Standard deviations for three-year-olds, however, suggest that there was sufficient variability in their scores and that they were able to complete portions of the task.

In the analyses using expressive vocabulary (EVT raw score) as the outcome variable, only digit span forward and backward could be used as predictors to test the mediating effects of receptive vocabulary. Nonword repetition (DNWRT score) was not significantly related to receptive vocabulary and therefore the mediated model could not be tested.

The results of the regression analyses with digit span forward predicting expressive vocabulary are shown in Table 4. Digit span forward significantly predicted a small but significant amount of variance in both receptive (2.4%) and expressive (3.7%) vocabulary scores. After controlling for the possible contribution of digit span forward, receptive vocabulary continues to account for a significant 12.1 % amount of the variance in expressive vocabulary scores. In testing the mediation model, the path between digit span forward and expressive vocabulary remained significant after taking into account the effects of receptive vocabulary suggesting a partially mediated model, *F (1, 110) = 4.49, p = .036*. The path between digit span forward and expressive vocabulary was tested using the Goodman test. The Goodman test revealed that this path was significant with a ratio of 2.57. Digit span forward scores accounted for 1.2% of the variance in expressive vocabulary scores after taking into account the effects of receptive vocabulary.

The results of the analyses using digit span backward as a predictor of expressive vocabulary are shown in Table 5. As with the forward span task, digit span backward significantly predicts a very small but significant amount of variance in both receptive (2.3%) and expressive (1.7%) vocabulary scores. After controlling for the possible contribution of digit span backward, receptive vocabulary continues to account for a significant 13.1 % amount of the

Table 4
Partially Mediated Model of Expressive Vocabulary

Predictor	Outcome	df	F	p	R^2
1. Age in Months	EVT raw score	1, 113	131.98	< .001	.54
2. Digit Span Forward		1, 112	9.65	< .01	.04
1. Age in Months	PPVT raw score	1, 115	108.67	< .001	.49
2. Digit Span Forward		1, 114	5.62	.02	.02
1. Age in Months	EVT raw score	1, 112	130.81	< .001	.54
2. Digit Span Forward		1, 111	9.56	< .01	.04
3. PPVT raw score		1, 110	43.61	< .001	.12
1. Age in Months	EVT raw score	1, 112	130.81	< .001	.54
2. PPVT raw score		1, 111	50.76	< .001	.14
3. Digit Span Forward		1, 110	4.49	.04	.01

Table 5
Fully Mediated Model of Expressive Vocabulary

Predictor	Outcome	df	F	p	R^2
1. Age in Months	EVT raw score	1, 113	131.98	< .001	.54
2. Digit Span Backward		1, 112	4.21	.04	.02
1. Age in Months	PPVT raw score	1, 115	108.67	< .001	.49
2. Digit Span Backward		1, 114	5.32	.02	.02
1. Age in Months	EVT raw score	1, 112	130.81	< .001	.54
2. Digit Span Backward		1, 111	4.17	.04	.02
3. PPVT raw score		1, 110	45.72	< .001	.13
1. Age in Months	EVT raw score	1, 112	130.81	< .001	.54
2. PPVT raw score		1, 111	50.76	< .001	.15
3. Digit Span Backward		1, 110	0.88	.35	.00

variance in expressive vocabulary scores. Testing the mediation model, the path between digit span backward and expressive vocabulary was not significant after taking into account the effects of receptive vocabulary *F (1, 110) = 0.878, p = .351*. The lack of significance of the path between digit span backward and expressive vocabulary after including receptive vocabulary suggests a fully mediated model. It is important to note, however, that the backward span scores remained highly skewed, even after attempts to transform the variable.

Exploratory Analyses

In the analyses using productive grammar (MLUm or Ipsyn score) as the outcome variable, none of the measures of memory were significant predictors. All measures of memory significantly correlated with the receptive grammar measure (TROG raw score) but not with the productive grammar scores. Thus, one of the necessary paths to test for mediation was not established and the mediation models could not be tested. In these original analyses, MLUm was computed using Chapman's (1981) modified rules. These modified rules suggest including all repetitions, imitations, and responses to yes/no questions in order to maintain comparability to Brown's (1973) original stages. Repetitions, imitations, or responses to questions should only be excluded if they make up more than 20% of the child's speech sample. This was not the case in the current sample. Despite the low proportion of any one these categories, MLUm was also computed from transcripts after omitting all repetitions, imitations, and responses to yes/no questions. Omitting these categories results in utterances that the child spontaneously creates, which may increase the reliance on memory. The mediation models were computed using this modified MLUm score.

Using the modified MLU-m score, the transformed nonword repetition syllable scores were significantly related to productive vocabulary ($r = -.22$, $p = .02$). The correlation between the modified MLU-m and the original nonword repetition syllable scores approached significance ($p = .056$). The transformed nonword repetition scores accounted for 3.3% of the variance in both modified MLU-m scores and receptive grammar scores. After controlling for the possible influence of nonword repetition scores, receptive grammar scores accounted for 4.7% of the variance in the modified MLUm scores. In testing the mediation model, nonword repetition did not account for a significant amount of variance in the modified MLU-m scores ($F(1, 113) = 1.95, p = .17$) after taking receptive grammar scores into consideration (see Table 6). These findings suggest a fully mediated model of speech production.

Table 6

Fully Mediated Model of Productive Grammar

Predictor	Outcome	df	F	p	R^2
1. Age in Months	Modified MLUm	1, 115	0.21	.65	.00
2. Transformed NW syllables		1, 114	3.90	.05	.03
1. Age in Months	TROG raw score	1, 117	76.08	< .001	.39
2. Transformed NW syllables		1, 116	6.73	.02	.03
1. Age in Months	Modified MLUm	1, 115	0.21	.65	.00
2. Transformed NW syllables		1, 114	3.90	.05	.03
3. TROG raw score		1, 113	5.82	.02	.05
1. Age in Months	Modified MLUm	1, 115	0.21	.65	.00
2. TROG raw score		1, 114	7.88	.01	.07
3. Transformed NW syllables		1, 113	1.95	.17	.02

Discussion

The primary purpose of the current study was to examine whether a relationship exists between verbal aspects of memory and language production. Second, assuming the first purpose was fulfilled, it was of interest to examine whether receptive language mediates the relationship between memory and language production. The existence of a partially mediated model would offer potential support for the influence of WM in a speech output buffer.

The results of the study revealed significant paths between the variables necessary to test for a mediated relationship between memory and language production. These paths, however, only were significant with specific measures. Findings concerning these paths, as well as the mediation models that were tested will be discussed in detail in the sections that follow.

STM, WM, and Receptive Vocabulary

The correlations between STM and receptive vocabulary, established in numerous previous studies (e.g. Baddeley et al., 1998; Ellis & Sinclair, 1996; Gathercole & Baddeley, 1989), were low but significant, ranging from .17 to .22 in the present study. The results revealed that digit span forward was correlated significantly with receptive vocabulary; however, the correlation between nonword repetition and receptive vocabulary did not reach conventional levels of significance ($p = .06$). Backward digit span, the measure of WM, also was significantly related to receptive vocabulary in the current study.

In previous studies, the correlations between digit span forward and receptive vocabulary for children have ranged between .22 and .46 (see Baddeley et al., 1998). These studies suggest that children's STM capacity, measured by digit span forward aids in the acquisition of vocabulary (Gathercole & Baddeley, 1990). According to this explanation, to learn new words, children must rely on temporary phonological representations. Children must be able to hold these representations while mapping meaning onto the word. Those children with increased memory capacity will have better temporary representations, which would increase the likelihood that those representations are committed to long-term memory. Thus, the children with increased capacity should be able to learn new words more efficiently than those children with relatively smaller STM capacity (Adams & Gathercole, 2000).

Although the partial correlation between nonword repetition and receptive vocabulary is close to statistical significance, the lack of a significant correlation between these two variables does not follow previous research that suggests nonword repetition should correlate highly with receptive vocabulary (see Baddeley et al., 1998). Previous studies that have shown nonword repetition correlates more highly with vocabulary than does digit span (see Baddeley et al., 1991) typically used the Children's Test of Nonword Repetition (CNRep, Gathercole et al., 1994). Differences between the digit span task and the CNRep as well as DNWRT explain why the pattern of correlations may have differed in the current study. Although STM is implicated in the acquisition of vocabulary, vocabulary knowledge also influences performance on specific memory tasks. The digit span task not only tests a child's STM capacity, but also assesses their knowledge of number words. Children who have a larger receptive vocabulary also will likely be more familiar with number words when compared to children whose vocabulary is not as large. Because numbers are a specific subset of words, children who have learned more words in general should also know more number words. Further, children in preschool are being exposed to vocabulary and numbers in school daily. A child's performance on the digit span task and on the vocabulary measure may thus be influenced by the amount of explicit exposure the child has to words and numbers in school. For both these reasons, digit span is more highly correlated than the nonword scores in the present sample.

Nonword repetition tasks such as Gathercole's CNRep (1994) task and DNWRT measure a child's STM capacity but also assess how well a child can store phonological patterns. Although both tasks are designed to minimize the influence of phonological knowledge, CNRep utilizes nonwords containing familiar and frequent phonological patterns. For example, in the CNRep, nonwords such as 'brasetering' and 'kannifer' contain sound combinations (i.e., -ing, -er) that appear frequently in English. This inclusion of familiar sound combinations will influence a child's performance on the task. Researchers examining the wordlikeness of nonwords have found that nonwords that contain more of these frequent sound combinations are more easily remembered than those that do not contain familiar patterns (Gathercole et al., 1991). DNWRT was designed to minimize this influence by excluding individual phoneme combinations that appear frequently in English words and placing phoneme combinations in positions that occur less than 25% of the time in the English language. In doing this, DNWRT relies even less on a child's ability to process phonological representations present in English than CNRep and measures STM in a more pure sense (Dollaghan & Campbell, 1998). The differences in DNWRT and CNRep may therefore explain the lower correlations between nonword repetition and receptive vocabulary in the current study. That is, measures that are more lexically based, such as the digit span task and CNRep, may be significantly related to receptive vocabulary because of the lexical influence present in the tasks.

The relationship between backward digit span and receptive vocabulary, which was significant in the present study, has not been well examined in previous literature. As with digit span forward, backward digit span may be related because of the lexical stimuli used in the task.

Because real words are used in this task, it is possible that children with a larger vocabulary base are more familiar with number words as well. Backward span also may be related because of the additional processing component associated with the measure. The child must process the given information by manipulating the order of the stimulus in backward digit span. For a child to learn a word, he or she must be able to hold the phonological representation of the term while identifying the object and attaching the meaning that the term refers to (Daneman & Green, 1986). This shared need to process information may account for the significant correlations between backward digit span and receptive vocabulary. Because WM is implicated as the workspace to process information, and processing is required to learn words, WM should be related to vocabulary levels, as was found in the current study.

STM, WM, and Receptive Grammar

All measures of memory (i.e., digit span forward, nonword repetition, and backwards digit span) were significantly related to receptive grammar in the current study. The results of the current study suggest that those children with greater memory capacity were able to integrate all pieces of information contained in utterances that they heard more efficiently than those children with lesser capacity. The children with greater STM capacity (i.e., those children with higher digit span and nonword repetition scores) may be able to hold a larger piece of an utterance in order to process the entire meaning of an utterance than those children with smaller capacity who can only attend to one part of an utterance and thus are not able to comprehend the entire utterance. Baddeley and colleagues (1998) similarly suggested that children who perform better on measures of STM will be able to form better temporary representations of grammatical forms. These children who have greater temporary representations then will be able to learn the syntactic frames more quickly and efficiently than children who do not have well defined temporary representations. Thus memory capacity may play a role in the acquisition as well as the knowledge of grammatical rules.

Grammatical comprehension relies on specific skills that are attributed to STM and WM. As in lexical acquisition, in learning grammatical forms the child must be able to map the lexical terms that are heard with the actual event to which the utterance is referring. The child also must be able to determine which word in an utterance specifies which part of the context. That is, when hearing an utterance, a child must be able to hold each of the words in the utterance temporarily while determining which word is the verb, which word is the object, and so on. An example of a stimulus sentence from the receptive grammar task helps to illustrate the demands involved when a child hears a grammatically complex or unfamiliar utterance. For the sentence, '*The cat the cow chases is black,'* the child must be able to hold the subject (the cow) the direct object (the cat) the verb (chases) and the adjective (black). The child must then realize which one of the lexical terms represents which part of speech in order to comprehend the meaning of the utterance. Digit span requires the child to hold terms that are presented with a pause in between each term, much like words would be presented in a sentence. Nonword repetition requires the child to attend to smaller elements, such as syllables and phonemes, within one term. In grammatical comprehension, a child relies on the ability to attend to each lexical term as well as the ability to segment phonemes and syllables in connected speech (Robinson et al., 2003). In particular, to interpret the meaning of the utterance successfully, the child must be able to hold each lexical term that is heard and also be aware of bound morphemes (e.g., -ed, -s) present within each lexical term. In the backward digit span task, the children are required to hold information temporarily while manipulating the order of this incoming information. Grammatical comprehension, similarly, relies on a child's ability to hold incoming information while determining the correct meaning given the placement of each word. Because English is highly dependent on word order, lack of attention to order may significantly alter the meaning of the utterance.

Receptive and Expressive Language

The correlations between the measures of receptive and expressive language were significant in the current study. The partial correlation between receptive vocabulary and expressive vocabulary, after controlling for age, was .56. The partial correlations between receptive grammar and productive grammar when controlling for age were .24 and .34 (for MLUm and IPSyn, respectively). These correlations were consistent with the literature and the known link between receptive and expressive vocabulary (e.g., Bates & Goodman, 1997; Gathercole et al., 1997). Those children with better representations of words or grammatical forms should be able to recall these forms more efficiently and quickly during production. Children who know more grammatical structures also will be able to abstract the grammatical rules associated with those structures rather than using a small number of structures in limited, context specific settings thereby facilitating their flexible and productive use of the structures. Further, a child with large lexical base will have a larger repertoire of words to use when producing language.

Models of Production

Memory and Expressive Vocabulary. In the present study, children's STM, as measured by digit span and nonword repetition, was significantly correlated with their expressive vocabulary scores. Further, a measure of WM, backward digit span, was also significantly correlated with expressive vocabulary, accounting for about 2.5% of the variance in scores. Results from the present study are in line with previous research finding that STM correlates with expressive vocabulary (Adams & Gathercole, 1995; Gathercole et al., 1997). Adams and Gathercole (1995) found that children with greater phonological STM capacity had more diverse vocabulary in their free speech than the children with lesser capacity. The current study was not designed to assess the variety of words in the free speech samples because of the problems associated with type token ratio (TTR; see McKee, Malvern, & Richards, 2000 for a review of this issue). Instead, expressive vocabulary was measured using a standardized measure (i.e., EVT).

After establishing this final preliminary path necessary to test for mediation, it was possible to examine the role of receptive vocabulary in the relationship between memory and expressive vocabulary. Two different models of speech production were supported in the present study when expressive vocabulary was the outcome measure. A partially mediated model was supported when forward digit span was entered as the STM measure whereas a fully mediated model was supported when backward digit span was entered as the WM measure. A partially mediated model potentially offers support for the role of memory in a speech output buffer whereas a fully mediated model of speech suggests that the influence of STM and WM on language production operates through their influence on language comprehension.

Although there was support for a partially mediated model of vocabulary production when digit span forward was entered as the predictor, overall, the results of the analyses suggest that the relationship between language production and memory may be fully mediated by receptive language. The existence of the partially mediated model of speech production does not fit with the overall pattern of findings. It may be that due to the high number of analyses conducted, this significant path was simply a spurious relation. The magnitude of the effect supports this assertion. The amount of variance in expressive vocabulary explained by digit span forward after accounting for receptive vocabulary was only 1%. This amount of variance explained was smaller than that in one of the fully mediated models. The remaining models suggest that the ability to produce language relies on the ability comprehend language, thus resulting in fully mediated models. It appears that, as previous authors have suggested (e.g., Adams & Gathercole, 1996; Daneman & Green, 1986), when the task of producing language is exceptionally difficult, memory capacity may act as a constraining factor. With single word vocabulary production, however, it seems unlikely that the ability to hold information temporarily continues to influence a child's ability to produce single known words after accounting for lexical knowledge, even in young children.

The fully mediated model of speech production between backwards digit span and expressive vocabulary suggests that the ability to hold and process information influences receptive vocabulary, which in turn then influences expressive vocabulary. The influence of memory constraints that would play a role in vocabulary production have already constrained a child's vocabulary comprehension. That is, children with greater WM capacity should have better defined lexical representations than children with relatively smaller WM capacity (see Robinson et al., 2003). Because of their better defined temporary representations, children with greater WM capacity increase the likelihood that the word will be committed to long-term memory more quickly than the children with lesser capacity. Once the representation is committed to long-term memory, these children can then begin to attach specific meaning to the term and compare the new representations with already known words, thus strengthening the link between the word and meaning. The stronger the link between the word and the meaning, the more quickly and efficiently children with greater memory capacity can retrieve words for production, eventually allowing the process to become automatic. Once the process becomes automatic, it is unlikely that children will rely on their memory capacity to link the word with the meaning prior to production. Thus the effects of memory are no longer seen on the child's single word production. The fully mediated model suggests that the influence of WM in a speech output buffer is not necessary when the child is able to comprehend and produce vocabulary well.

Memory and Productive Grammar. The results of the current study were consistent with previous literature (e.g., Adams & Gathercole, 1995, 1996) and revealed a direct path between memory capacity and grammar production. Whereas previous studies (Adams & Gathercole, 1995) have examined a composite score of STM by combining digit span forward and nonword repetition scores, the present study analyzed these measures separately. The direct path between grammar production and memory was only significant when examining nonword repetition and the modified MLUm scores. The test of mediation suggested that this path is fully mediated by receptive grammar.

The original MLUm scores calculated for the analyses used Chapman's (1981) rules, which suggest including repetitions, imitations, and responses to yes/no questions. Calculating MLUm in this way revealed nonsignificant correlations with the memory measures. The increased number of repetitions, imitations, and responses to yes/no questions in the original MLUm scores did not reflect unique utterances that the child had to construct independently. In the case of these utterances, the child would not have to rely on limited memory capacity to construct and combine pieces of an utterance but simply restate a previously heard utterance. When the child imitates the adult speaker, repeats a previously stated utterance, or responds with a simple yes or no, the child likely does not utilize limited memory resources. The child has either previously heard the construction (in imitations) or has already utilized resources constructing the utterance (as in repetitions), thus production is routinized or automatic. Similarly, responses to yes/no questions allow the child to rely on rote responses and not to actively construct a response. Removing all self-repetitions, imitations, and responses to yes/no questions in the modified MLUm resulted in a significant correlation with nonword repetition. The modified MLUm measure thus only counts those unique spontaneous utterances that the child has produced, increasing the likelihood the child is constructing rather than remembering those utterances during the conversation.

The lack of a significant correlation between the memory measures and the IPSyn scores also may be because of the method of calculating these scores. IPSyn is a measure of emergence rather than a measure of mastery (Scarborough, 1990). That is, scores are calculated by counting up to two instances of each coded part of speech. Limiting the maximum score for grammar production in this way may not accurately reflect a child's full ability to construct complex grammatical structures repeatedly. A child who is able to produce many instances of complex sentences may rely on his or her memory capacity to a greater degree than a child who only produces one or two instances when constructing utterances. The child who is only producing one or two instances of a complex sentence construction may be simply recalling a "frozen," or routenized, phrase. When children are learning grammatical structures or phrases, they often use those structures only in familiar and known circumstances. Children are not able to generalize the construction to other settings until later (Akhtar & Tomasello, 1997). A child who has learned the construction, alternatively, will be able to produce the particular grammatical structure fluently in varied settings. This child will be able to recall a structure from memory and apply it to the current setting. Because IPSyn only counts up to two instances of each construction, however, the child who knows the rule and the child who is using the phrase rotely will be considered equal. The lack of differentiation with IPSyn scores does not allow for the effects of STM or WM on grammar production to be seen because both types of children are receiving similar scores.

As stated previously, nonword repetition was the only memory measure that significantly correlated with grammar production. In addition to the minimized lexical influence present in the nonword repetition, the skills necessary to succeed on the nonword repetition are slightly different from those needed to complete the digit span task successfully. This difference may account for the significant relation between nonword repetition and grammar production. For young children to be able to recall the nonword, they must be able to parse the nonword into segments and retain those phonemes or syllables (Ellis & Sinclair, 1996; Robinson et al., 2003). The child must further recall the correct order of these segments to produce the nonword accurately. Similarly, in grammar production, the child must be aware of individual segments that are important to the English language. Children must learn to use function words and bound morphemes appropriately to produce an utterance accurately (Gleason, 2001). The child must also be cognizant of where these smaller units must be placed in the utterance to convey the correct message. Digit span tasks may not require the child to attend as closely to these smaller units. Numbers, which are used as stimulus items, are familiar items which the child likely processes as one unit. Further, in the digit span tasks, the children are presented with one-syllable words (except with the number seven) with a short pause in between each digit. In this way, the units are already segmented for the child during the list presentation.

In the exploratory analysis, a fully mediated model of speech production was supported in the relationship between nonword repetition and modified MLUm. One implication of this fully mediated model using the modified MLUm scores is that the ability to recall and attend to small units of language is important when the child's most complex utterances are measured. It is only when these complex utterances are examined that children are likely depending on their limited capacity memory systems. The existence of a fully mediated model of speech production when using the modified measure of MLUm suggests that grammar production may not rely on the existence of a speech output buffer. It appears that the production of grammatical utterances relies more heavily on the comprehension of grammatical utterances than on memory constraints. That is, it is assumed that a child's STM capacity will influence the nature of their lexical and morphosyntactic representations in that the child who has greater STM capacity will have better defined lexical and morphosyntactic representations. This child will be able to retrieve the correct representations more quickly than a child that does not have well defined representations, and eventually the process of speech production will become automatic. It is possible that any effects of a speech output buffer will only be seen when language production tasks are difficult, as when the structures necessary for production are not readily known grammatical structures. In this case, a child would have to rely on STM to hold the grammatical structure temporarily while determining the correct lexical terms to place into the structure. In most cases of natural speech production, however, the child is able to use well-learned grammatical structures that can be retrieved automatically, thereby minimizing the dependency on STM.

Overall, the mediated models found in the current study suggest that memory does not seem to influence a speech output buffer when children are producing language. It may be that by five years of age, children are fluent speakers and the reliance on a speech output buffer is only necessary when the production task is difficult. That is, it may be that the functions the speech output buffer are proposed to play have a larger role when children are learning to produce speech and the grammatical structures are not well learned. It is this case that the child would have to rely on a space such as a speech output buffer to hold various parts of the utterance prior to production.

The findings of the current study, however, do suggest that receptive language plays an important role in the relationship between memory and language production. Though receptive language has been alluded to as an explanation for the relationship between STM and language production (see Adams & Gathercole, 1995, 1996, 2000), it has not been empirically examined. Results of the current study are consistent with the explanations suggesting a child's long-term phonological representations, which are influenced by memory capacity, influence language production. The fully mediated models of production also are consistent with Locke's (1997) theory of linguistic development. This theory suggests that children go through phases in language acquisition. These stages involve children collecting words and utterances in a formulaic fashion and then later decomposing these into syllables and segments. Once the child has learned the syllables and segments, he or she is able to integrate this information and produce complex utterances. Locke's (1997) theory suggests that children rely on their STM and WM capacity during early stages of language acquisition to collect and decompose words and phrases necessary to produce language. Younger children, who are still in the process of collecting words and utterances may thus depend on STM and WM during language production, even when the task is not particularly difficult. Because the younger children are learning the information necessary to integrate and produce complex utterance, their memory capacity may continue to influence language even after accounting for their receptive language knowledge. Although the current study suggests that when children are between the ages of three and five they have learned enough syllables and segments so that language production is automatic (see means and standard deviations by age in Table 7), correlations for each age group in the current study (displayed in Table 8) reveal that the patterns of correlations between memory, receptive language, and expressive language differ between the ages of three and five with a larger correlation between memory and language production for younger children. In the three- year-old age group, both measures of STM are significantly correlated with receptive vocabulary and digit span forward is correlated significantly with all measures of production. Further, digit span backwards is significantly correlated with expressive vocabulary. For the four-year-old age group, all measures of STM and WM are correlated significantly with expressive vocabulary only. In the oldest age group in the current sample, no memory measures are significantly correlated with any of the language measures. As can be seen from Table 8, receptive vocabulary and grammar play an increasingly important role in language production as age increases. This suggests, as previously stated, that the influence of STM and WM change as children grow, playing smaller roles at older ages. Although it was possible to examine the correlations by age, analyzing the mediation models by age in the current study resulted in sample sizes too small to test the hypotheses.

Conclusions, Limitations and Future Directions

The current study clarified the nature of the relationship between STM and expressive vocabulary, as well as the relationship between STM and productive grammar. The study also offered insight as to how WM is related to these two aspects of production. Although the current study suggests that the relationship between memory and language production is mediated by receptive language, the effect sizes of these mediated models are small. In particular, the correlations between the memory measures and the language production variables are low. As

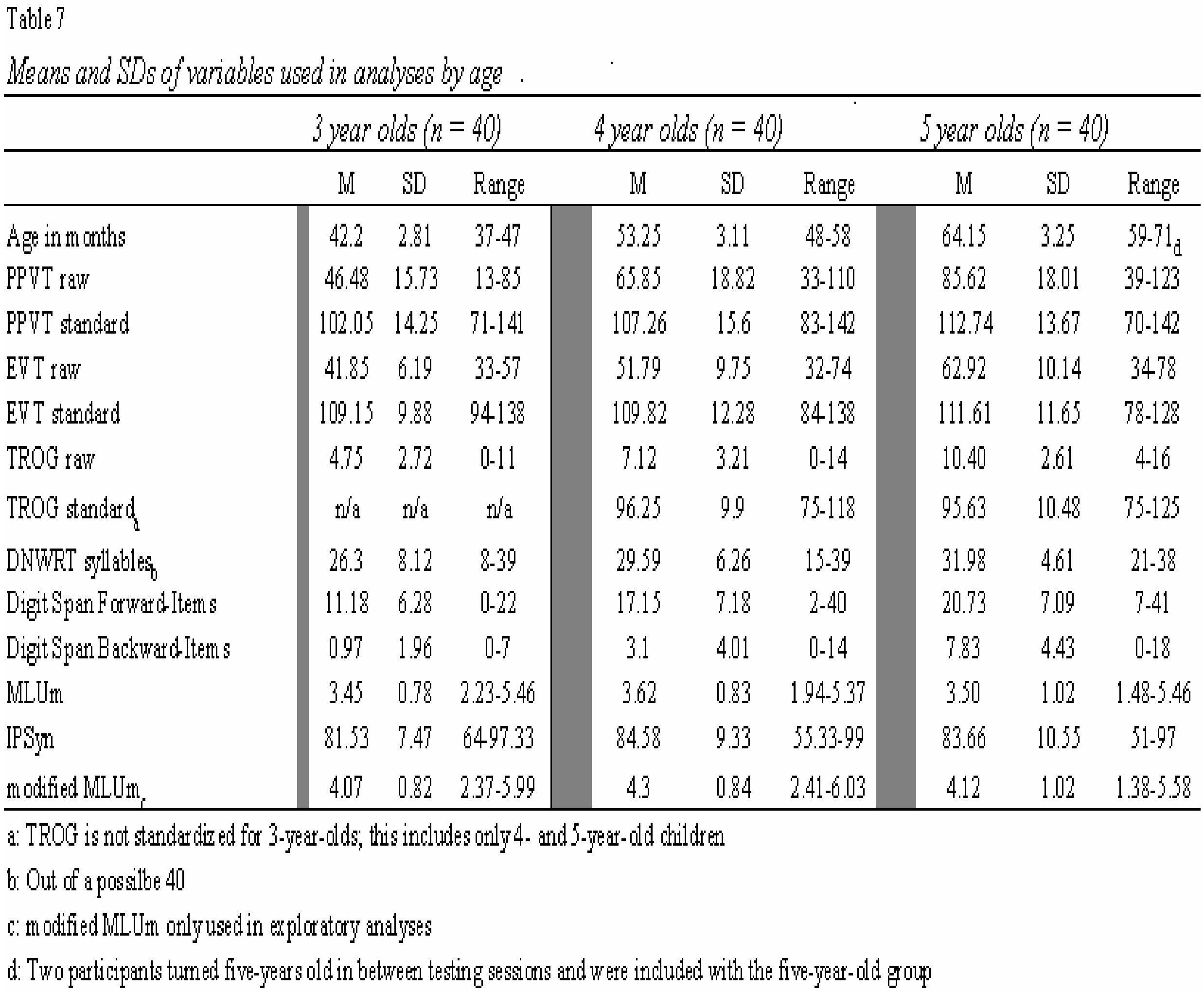

Table 7

Means and SDs of variables used in analyses by age

	3 year olds (n = 40)			*4 year olds (n = 40)*			*5 year olds (n = 40)*		
	M	SD	Range	M	SD	Range	M	SD	Range
Age in months	42.2	2.81	37-47	53.25	3.11	48-58	64.15	3.25	59-71[d]
PPVT raw	46.48	15.73	13-85	65.85	18.82	33-110	85.62	18.01	39-123
PPVT standard	102.05	14.25	71-141	107.26	15.6	83-142	112.74	13.67	70-142
EVT raw	41.85	6.19	33-57	51.79	9.75	32-74	62.92	10.14	34-78
EVT standard	109.15	9.88	94-138	109.82	12.28	84-138	111.61	11.65	78-128
TROG raw	4.75	2.72	0-11	7.12	3.21	0-14	10.40	2.61	4-16
TROG standard[a]	n/a	n/a	n/a	96.25	9.9	75-118	95.63	10.48	75-125
DNWRT syllables[b]	26.3	8.12	8-39	29.59	6.26	15-39	31.98	4.61	21-38
Digit Span Forward-Items	11.18	6.28	0-22	17.15	7.18	2-40	20.73	7.09	7-41
Digit Span Backward-Items	0.97	1.96	0-7	3.1	4.01	0-14	7.83	4.43	0-18
MLUm	3.45	0.78	2.23-5.46	3.62	0.83	1.94-5.37	3.50	1.02	1.48-5.46
IPSyn	81.53	7.47	64-97.33	84.58	9.33	55.33-99	83.66	10.55	51-97
modified MLUm[c]	4.07	0.82	2.37-5.99	4.3	0.84	2.41-6.03	4.12	1.02	1.38-5.58

a: TROG is not standardized for 3-year-olds; this includes only 4- and 5-year-old children

b: Out of a possilbe 40

c: modified MLUm only used in exploratory analyses

d: Two participants turned five-years old in between testing sessions and were included with the five-year-old group

Table 8

Partial correlations among variables by age$_a$

			DNWRT syllables	DigitSpan Forward	DigitSpan Backward	PPVT raw	PPVT standard	TROG raw	TROG standard	EVT raw	EVT standard	MLUm	IPSyn	Modified MLUm
	Memory Measures	DNWRT syllables	1											
		DigitSpan Forward	.43**	1										
		DigitSpan Backward	.25	.13	1									
		PPVT raw	.35*	.31+	.07	1								
3-year-olds	Receptive Language	PPVT standard	.35*	.32+	.07	1.0***	1							
		TROG raw	.17	.21	.17	.59***	.59***	1						
		TROG standard	-	-	-	-	-	-	-					
		EVT raw	.23	.31+	.27++	.54***	.54***	.47***	-	1				
	Expressive Language	EVT standard	.24	.31+	.30++	.55***	.55***	.47***	-	1.0***	1			
		MLUm	.22	.28++	.11	.23	.23	.06	-	.17	.17	1		
		IPSyn	.12	.31+	-.1	.15	.15	.14	-	.16	.14	.67***	1	
		modified MLUm	.24	.36*	.12	.26++	.27++	.09	-	.22	.22	.93***	.65***	1
	Memory Measures	DNWRT syllables	1											
		DigitSpan Forward	.49***	1										
		DigitSpan Backward	.31++	.55***	1									
		PPVT raw	.07	.06	.22	1								
4-year-olds	Receptive Language	PPVT standard	.05	.04	.19	1.0***	1							
		TROG raw	.28++	.25	.30+	.52***	.50**	1						
		TROG standard	.27++	.23	.34*	.46**	.44**	.98***	1					
		EVT raw	.32+	.40**	.33*	.55***	.52***	.55***	.55***	1				
	Expressive Language	EVT standard	.32+	.40**	.35*	.60***	.57***	.59***	.59***	.99***	1			
		MLUm	.08	.04	.01	.66***	.63***	.56***	.54***	.33*	.37*	1		
		IPSyn	-.03	.20	.09	.46**	.45**	.59***	.56***	.36*	.38*	.80***	1	
		modified MLUm	.24	.26	.22	.51***	.49**	.51***	51***	.41*	.44**	.85***	.72***	1
	Memory Measures	DNWRT syllables	1											
		DigitSpan Forward	.37*	1										
		DigitSpan Backward	.21	.34*	1									
		PPVT raw	.05	.23	.23	1								
5-year-olds	Receptive Language	PPVT standard	.07	.20	.22	.98***	1							
		TROG raw	.17	.34*	.42**	.67***	.64***	1						
		TROG standard	.20	.30+	.40*	.59***	.56***	.95***	1					
		EVT raw	.20	.13	.13	.65***	.71***	.49**	.49**	1				
	Expressive Language	EVT standard	.20	.19	.16	.71***	.71***	.58***	.57***	.94***	1			
		MLUm	-.11	-.17	-.11	.48**	.50***	.09	.11	.45**	.43**	1		
		IPSyn	-.21	-.14	-.08	.52***	.51***	.19	.16	.50***	.52***	.89***	1	
		modified MLUm	.02	-.10	-.12	.51***	.53***	.17	.16	.41*	.41*	.88***	.84***	1

++p<.10, + p < .06, * p< .05, ** p < .01, *** p<.001

discussed previously, the nature of the measurement techniques likely influenced these correlations. In addition to the method of calculating grammar production, the setting that speech samples were obtained from may have contributed to the low correlations. The conversations the children were engaged in during the play sessions were unstructured and therefore did not attempt to elicit particular grammatical constructions. Though the play sessions did offer a naturalistic sample, it is possible that the setting was not appropriate for children to demonstrate their complete range of grammatical ability. Research suggests that although children display their grammatical ability in free speech or narrative samples, structured elicitation tasks are more likely to capture a child's grammatical production capacity (Hesketh, 2004). Structured interviews or conversations would likely compel a child to utilize more complex utterances in his or her speech. Tapping a child's full grammatical production capabilities may result in different relationships among the variables and a stronger influence of memory. Future analysis should also examine the number of speech errors in the children's speech samples. If memory capacity constrains the efficiency of children's language production, those children who exhibit more mazes and false starts in their language production may reveal a larger effect of memory in the analyses.

Future studies should also examine children separately based on age (see Table 7 for means and standard deviations of variables by age group). Because children's language is developing over the ages of three and five, it is possible that the relationship between memory and productive language is fully mediated by receptive language in one age group but partially mediated in another. For younger children, who have not learned as many words and grammatical structures as older children, STM and WM may be necessary to construct utterances even after accounting for receptive language levels.

Finally, future research must examine additional measures of STM and WM when testing models of speech production. Alternative forms of nonword repetition and other measures of STM and WM must be examined to confirm the findings of the present study. In the current study, the distribution of digit span backwards was highly skewed. Seventy-two percent of the three-year-old children in the sample were not able to complete the backward digit span task successfully and received a score of zero. This makes it difficult to interpret the findings of the fully mediated model of speech production. It is important to examine other measures of WM in the relation to language production.

To conclude, the overall findings of the current study are consistent with previous literature, revealing correlations between measures of STM or WM and language production. The current study further suggests that the relationship between memory and language production is mediated by receptive language. In typically developing children in this age range, a speech output buffer does not seem to be utilized during natural language production, however, the number of words and phrases in the child's receptive language does to play a significant role in producing language.

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APPENDICES

Appendix A

IPSyn Subscale Items

	Noun Phrase	Verb Phrase	Question/Negation	Sentence Structure
Item				
1	Proper, mass, count noun	Verb	Intonationally marked question	Two-word combination
2	Pronoun or prolocative, excluding modifiers	Particle or preposition	Routine do/go or existence/name question or wh- pronoun alone	Subject-verb sequence
3	Modifier, including adjectives, possessives, and quantifiers	Prepositional phrase (Prep + NP)	Simple negation (neg + X): neg=no(t), can't, don't; X=NP, VP, PP, Adj, Adv, etc.	Verb-object sequence
4	Two-word NP	Copula linking two nominals	Initial wh- pronoun followed by verb	Subject-verb-object sequence
5	Article, used before a noun	Catenative (pseudo-auxiliary) preceding a verb	Negative morpheme between subject and verb	Conjunction (any)
6	Two-word NP (as in N4) after verb or preposition	Auxiliary be, do, have in VP	Wh- question with inverted modal, copula, or auxiliary	Sentence with two VPs
7	Plural suffix	Progressive suffix	Negation of copula, modal, or auxiliary	Conjoined phrases
8	Two-word NP (as in N4) before verb	Adverb	Yes/no question with inverted modal, copula or auxiliary	Infinitive without catenative, marked with to
9	Three-word NP (Det/Mod + Mod + N)	Modal preceding verb	Why, When, Which, Whose	Let/Make/Help/Watch introducer
10	Adverb modifying adjective or nominal	3rd person singular present tense suffix	Tag question	Adverbial conjunction
11	Any other bound morpheme on N or adjective	Past tense modal	Other: e.g., questions with negation and inverted cop/aux/modal	Propositional complement
12	Other (not used)	Regular past tense suffix		Conjoined sentences (will usually have subj + predicate in each clause)
13		Past tense auxiliary		Wh- clause
14		"Medial" adverb		Bitransitive predicate
15		Copula, modal, or auxiliary for emphasis or ellipsis		Sentence with 3 or more VPs
16		Past tense copula		Relative clause, marked or unmarked
17		Other e.g., bound morpheme on verb or on adjective		Infinitive clause: new subject
18				Gerund
19				Fronted or center-embedded subordinate clause
20				Other e.g., passive constructions

Appendix B

Substitution Rules* and Stimulus Items for Dollaghan Task

	3 years	**4 years**	**5 years**
Initial	v / b	v / b	s, f / Π
	v / f	v / f	d / Δ
	t, s, f / Π	t, s, f / Π	w, j / l, r
	d, v, z / Δ	d, v, z / Δ	
	s, z, Π, Δ / Σ, tΣ, dZ	w, j / l, r	
	tΣ / Σ	t, s, Σ / tΣ	
	t, s, Σ / tΣ		
	d, z, Z / dZ		
	w, j / l, r		
Final	n / N	n / N	n / N
	v / b	v / b	s, f / Π
	v / f	v / f	d / Δ
	t, s, f / Π	t, s, f / Π	vowel / l, r
	d, v, z / Δ	d, v, z / Δ	
	s, z, Π, Δ / Σ, tΣ, dZ	vowel / l, r	
	tΣ / Σ		
	Σ / tΣ		
	s / tΣ		
	t / tΣ		
	d / dZ		
	d / Z		
	dZ / Z		
	vowel / l, r		

*Denotes substitutions that were scored as correct when used in either the initial or final positions of nonwords.

Dollaghan Nonword List:

nAIb
voYp
taYdZ
d□If
teIvak
tΣoYvΘg
vΘtΣaIp
n□ItaYf
tΣin□ItaYb
naItΣoYveIb
d□ItaYvΘb
teIv□ItΣaIg
veitatΣaId□Ip
dΘvoYn□ItΣig
naItΣ□ItaYvub
tΘvatΣInaIg