Published in final edited form as:

J Commun Disord. 2016 ; 62: 12–29. doi:10.1016/j.jcomdis.2016.04.001.

Predictors of Processing-Based Task Performance in Bilingual and Monolingual Children

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Abstract

In the present study we examined performance of bilingual Spanish-English-speaking and monolingual English-speaking school-age children on a range of processing-based measures within the framework of Baddeley's working memory model. The processing-based measures included measures of short-term memory, measures of working memory, and a novel word-learning task. Results revealed that monolinguals outperformed bilinguals on the short-term memory tasks but not the working memory and novel word-learning tasks. Further, children's vocabulary skills and socioeconomic status (SES) were more predictive of processing-based task performance in the bilingual group than the monolingual group. Together, these findings indicate that processing-based tasks that engage verbal working memory rather than short-term memory may be better-suited for diagnostic purposes with bilingual children. However, even verbal working memory measures are sensitive to bilingual children's language-specific knowledge and demographic characteristics, and therefore may have limited clinical utility.

Keywords

processing-based measures; working memory; assessment bias; bilingual children

1. Introduction

Assessing the language skills of children who are exposed to more than one language and who come from low socioeconomic (SES) backgrounds poses many challenges for speech language pathologists and educators in the United States. In order to reduce bias and avoid a misdiagnosis of bilingual children, the use of assessment tools that are less dependent on a child's current knowledge and that instead rely more on the ability to process information has been recommended (Campbell, Dollaghan, Needleman, & Janosky, 1997; Kohnert, Windsor, & Yim, 2006; Laing & Kahmi, 2003; Rodekohr and Haynes, 2001). However, while some studies have yielded promising results in demonstrating comparable levels of performance by bilinguals and monolinguals on processing-based tasks (e.g., Danahy,

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Windsor, & Kohnert, 2007; Lee & Gorman, 2012; Sharp & Gathercole, 2013), other studies have shown that processing-based tasks do not eliminate group differences (Kohnert et al., 2006; Windsor, Kohnert, Lobitz, & Pham, 2010). The reasons behind these inconsistent findings in the literature remain unclear, and therefore the clinical utility of processing-based tasks for diagnostic purposes with bilingual children also remains in question. In the present study, we tested bilingual and monolingual children on a battery of processing-based tasks with the view to pinpoint the predictors of processing-based task performance in these two groups. Understanding what predicts bilingual and monolingual processing-based task performance may shed light on the reasons behind prior studies' inconsistent findings regarding bilinguals' performance on processing-based tasks, and may propel forward the search for valid processing-based measures that would effectively capture the bilingual language capacity.

1.1 Processing-Based Measures in Monolingual and Bilingual Children

It has long been recognized that knowledge-based assessments rely on previous experiences and therefore have the potential for over-diagnosing language impairment in typically-developing children from disadvantaged backgrounds. As a result, tasks that reduce the need to depend on previous experiences and rely more on information processing have been introduced. In one of the first attempts to contrast knowledge-based and processing-based measures, Campbell et al. (1997) administered one standardized, knowledge-based assessment and three processing-based tasks to boys from minority racial groups and low socioeconomic (SES) backgrounds and boys from a majority racial group and higher SES backgrounds. The processing-based measures included a non-word repetition task in which participants repeated novel words; the Competing Language Processing Task, in which children were required to engage in grammatical processing while simultaneously maintaining a set of words in memory; and the Revised Token Test, in which children completed motor actions in response to an auditory command. Results revealed that, while the minority and the majority groups significantly differed on the standardized language-based assessment, they did not differ on any of the three processing-based tasks.

Campbell et al. (1997) concluded that processing-based measures minimize reliance on previous knowledge and reduce disparities between minority and majority children. A number of other studies revealed similar findings and also demonstrated that processing-based tasks can reliably distinguish children with language impairments from children with typically-developing language skills in both majority and minority populations (e.g., Bishop, North, & Donlan, 1996; Dollaghan & Campbell, 1998; Ellis Weismer et al., 2000; Rodekohr and Haynes, 2001). It was therefore very tempting to apply the same logic – i.e., to use processing-based tasks – to the problem associated with diagnosing language impairment in bilingual children.

Many studies have examined the utility of processing-based measures for reducing the bias inherent in administering knowledge-based measures normed on monolingual populations to children who speak two languages, yielding mixed results. Some studies reported positive findings, showing that typically-developing bilingual and monolingual children who differ on knowledge-based assessments of language ability can nevertheless attain similar levels of

performance on processing-based measures (Danahy, Windsor, & Kohnert, 2007; Lee & Gorman, 2012; Sharp & Gathercole, 2013). For example, Lee and Gorman (2012) reported similar overall performance on a non-word repetition task between bilingual and monolingual children. Similarly, Danahy and colleagues (2007) reported no group differences between monolingual and bilingual children on a counting span task. However, other studies reported negative findings, showing that typically-developing bilingual and monolingual children who differ on knowledge-based assessments of language ability also tend to perform differently on processing-based measures (e.g., Hwa-Froelich & Matsuo, 2005; Kohnert et al., 2006; Gutiérrez-Clellen, Calderón, & Ellis Weismer, 2004; Kohnert, Windsor, & Yim, 2006; Sharp & Gathercole, 2013; Thorn & Gathercole, 1999; Windsor, Kohnert, Lobitz & Pham, 2010).

For instance, Kohnert et al. (2006) found that monolingual children with higher levels of English knowledge outperformed bilingual children with lower levels of English knowledge on a non-word repetition task that purportedly did not rely on English language knowledge. Similar findings have been obtained when listening-span-type tasks have been used to examine language abilities in bilingual children, in that children with higher levels of English knowledge outperformed children with lower levels of English knowledge (Gutiérrez-Clellen, Calderón, & Ellis-Weismer, 2004; Kohnert, Windsor, & Yim, 2006). In general, the conclusion reached by the field is that processing-based measures administered in a single language are not reliable diagnostic tools (e.g., Kohnert et al., 2006; Thorn & Gathercole, 1999). However, in the absence of viable alternatives, it appeared to us that further examination of processing-based tasks for their potential usefulness in the assessment of bilingual children was warranted.

We began by considering that part of the difficulty associated with development of assessment measures that would be appropriate for both bilingual and monolingual children (including the processing-based measures) is that bilingual and monolingual children may occupy distinct demographic and sociocultural niches. Hispanic children who speak English and Spanish represent the largest segment of the bilingual population in the United States (Hopstock & Stephenson, 2003; Kohler & Lazarín, 2007). It is an unfortunate demographic reality that the majority of these children come from low SES backgrounds (Camarota, 2012). That is, bilingual Hispanic children face a multifaceted language acquisition challenge where their input is distributed across two languages, and where their sociolinguistic environment may yield non-optimal language outcomes. Thus, in addition to the different levels of language-specific skills that characterize monolingual and bilingual children, Spanish-speaking bilingual children in the United States also often differ from monolingual children in SES (Hernandez, Denton, & Macartney, 2007; Hoff, 2013). A viable processing-based measure that would be of most use to the field, therefore, would be one that would be unbiased against typically-developing bilingual children who not only have lower language-specific skills than their monolingual peers, but who also come from lower SES backgrounds. Therefore, in the present study, we examined a range of processing-based tasks for suitability in a sample of Hispanic bilingual children who differed from their monolingual English-speaking peers not only in their levels of English knowledge, but also in SES.

Our next step was the realization that the vast majority of processing-based tasks developed and employed by prior work are in fact verbal short-term and/or working memory tasks. For instance, research with bilingual children has used measures of short-term memory (such as non-word repetition) and measures of working memory (such as the Competing Language Processing Task) to index processing capacity, and several studies examined novel word learning – a task that relies on verbal memory (Gathercole & Baddeley, 1990; Gathercole, Hitch, & Martin, 1997) – for its potential to reduce assessment bias (Kan & Kohnert, 2008; Kapantzoglou, Restrepo, & Thompson, 2012; Wilkinson & Mazzitelli, 2003). In order to contribute to our understanding of bilingual performance on processing-based tasks, we embedded the examination of processing-based tasks within one theoretical model – Baddeley’s working memory model (Baddeley, 2000).

1.2 Working Memory Model and its Relationship to Processing-based Measures

Baddeley’s working memory model (Baddeley, 2000; Baddeley, Allen, & Hitch, 2011; Baddeley & Hitch, 1974) is one of best-known and established models of information processing. It describes working memory as a multi-component system consisting of the visuo-spatial sketchpad, the phonological loop, the episodic buffer, and the Central Executive. The phonological loop and the visuo-spatial sketchpad serve as temporary holding stores for linguistic and visual information. The episodic buffer serves to bind and integrate information from different sources, including the long-term memory system, while the Central Executive is responsible for allocating attention to the phonological loop, the visuo-spatial sketchpad, and the episodic buffer. Within Baddeley’s working memory framework, the ability to maintain verbal information in working memory is constrained by at least two factors: (1) the degree to which the task relies on the Central Executive and (2) the degree to which the to-be-maintained verbal information activates information in the long-term memory.

With respect to the involvement of the Central Executive, the working memory model makes a crucial distinction between working memory tasks and short-term memory tasks. While working memory tasks involve both the storage and the manipulation of the to-be-recalled information, short-term memory tasks involve only the storage of the to-be-recalled information (Engle, Tuholski, Laughlin, & Conway, 1999). A classic example of a short-term memory task is a forward digit-span task in which individuals are required to repeat series of numbers (Conway et al., 2005). The encoding and immediate recall of digits required by this task is posited to rely on the phonological loop. Because the information does not need to be operated upon, a forward-digit span task does not involve the Central Executive. A classic example of a working memory task is a backward digit-span task in which individuals are required to repeat series of numbers in reverse order (e.g., Conway et al., 2005). The backward digit-span task relies on the phonological loop for encoding and storage of the information, just like the forward digit-span task. However, because the backward digit-span task requires that the information be operated upon (i.e., its order has to be reversed for recall), performance on this task also relies on the Central Executive.

With respect to the involvement of long-term memory, there is extensive literature suggesting that performance on verbal memory tasks can be impacted by factors associated

with long-term linguistic knowledge (e.g., Gathercole & Baddeley, 1989; 1990; Gathercole, Willis, Emslie, & Baddeley, 1992). For instance, it is easier to recall a list of familiar words compared to a list of unfamiliar words (Gathercole, Pickering, Hall, & Peaker, 2011; Majerus & van der Linden, 2003; Turner, Henry, & Smith, 2000), presumably because remembering familiar words can be supported by long-term lexical-phonological knowledge. Similarly, non-words containing frequent phonemes are recalled more accurately compared to non-words that contain less frequent phonemes (Kovács & Racsmany, 2008; Majerus, Van der Linden, Mulder, Meulemans, & Peters, 2004; Messer, Leseman, Boom, & Mayo, 2010). Together, these findings indicate a relationship between current linguistic knowledge (i.e., phonological and/or vocabulary skills) and verbal short-term and working memory such that it is easier to encode, store, and recall linguistic information that can activate information in one's long-term memory.

While the Central Executive and the long-term memory have been central to theories of working memory, rarely have they been examined in relation to the development of processing-based measures for indexing language abilities in bilingual children. Yet, the vast majority of processing-based measures tested by prior studies are indeed tasks that rely on the working memory system. For example, the non-word repetition task, the most common processing-based task (Kohnert, Windsor, & Yim, 2006; Thorn & Gathercole, 1999; Windsor, Kohnert, Lobitz, & Pham, 2010), requires children to hold phonological information associated with non-words in memory for a brief period of time prior to repeating the information. In this, the non-word repetition task is a classic short-term memory task (e.g., Baddeley, Gathercole, & Papagno, 1998). Another common processing-based task is the Competing Language Processing Task (CLPT; Gutiérrez-Clellen, Calderón, & Ellis-Weismer, 2004; Kohnert, Windsor, & Yim, 2006). This task involves continuous integration of linguistic information as the sentence unfolds as well as a simultaneous analysis of semantic information in order to decide whether the sentence is true/false while maintaining the last word of each sentence in working memory. In this, the CLPT is a version of the listening span task – a classic working memory task (Cowan et al., 2003).

Several studies have shown that bilingual children's performance on the non-word repetition and the listening-span-type tasks is contingent on their level of long-term linguistic knowledge (Gutiérrez-Clellen, Calderón, & Ellis-Weismer, 2004; Kohnert, Windsor, & Yim, 2006; Thorn & Gathercole, 1999). For instance, bilingual children's non-word repetition performance was found to depend on their experience in each language (e.g., Thorn & Gathercole, 1999; Windsor, Kohnert, Lobitz, & Pham, 2010). Embedding processing-based tasks like non-word repetition within the framework of Baddeley's working memory model may help explain why bilingual children would experience more difficulty on these tasks than monolingual children. According to the working memory model, performance on verbal memory tasks is impacted by the degree to which the information being encoded, stored, and recalled overlaps with the information in the long-term memory. By that logic, if the non-words on the non-word repetition task are designed to reflect language-specific phonology and phonotactics, and bilingual children are less experienced in that language than monolingual children, their ability to repeat the non-words will also be compromised. Similarly, if bilingual children possess less robust vocabulary and syntactic skills in English

than their monolingual peers, they will perform less well on English listening-span tasks than their monolingual peers.

However, systematic manipulations of the degree to which a processing-based task overlaps with long-term language knowledge have been very rare in the literature, and it remains unknown whether the overlap at the different levels of the linguistic system (phonological, lexical, syntactic) influences bilingual vs. monolingual children's performance on processing-based tasks differently. Furthermore, considerations of the Central Executive's involvement in bilinguals' processing-based performance have also been rare. One exception is a study by Yoo and Kaushanskaya (2012), who compared bilingual and monolingual adults on both short-term and working memory measures. Their findings revealed that the monolingual group outperformed the bilingual group on the short-term memory tasks but not the working memory tasks. These findings may indicate that the utility of a processing-based task to accurately index bilinguals' language ability may be crucially dependent on the degree to which the task taxes the Central Executive.

In the present study, we contextualized a battery of processing-based tasks within the working memory model in order to begin to understand why their use with bilingual populations has been met with variable success. We hypothesized that the mutable performance of bilingual children (in relation to monolingual children) observed by prior work is the result of variability in two crucial variables that have long been known to influence verbal memory performance: the degree to which the processing-based task taxes the Central Executive, and the degree to which the to-be-processed information taps long-term linguistic knowledge. The other crucial question that has been left largely unexamined by prior studies is whether similar parameters (cognitive, demographic, and linguistic) predict performance on processing-based measures in bilingual and monolingual children. That is, in order to identify a processing-based task that would be suitable for indexing language abilities in both bilingual and monolingual children, not only should the task yield comparable levels of performance in the two groups, but performance on this task should also be predicted by similar parameters in the two groups. The comparable predictive relationships are important because if two groups of children recruit distinct skills when processing the same kind of information, the diagnostic utility of the task for identifying language impairment may fluctuate across the two groups.

1.3 The Current Study

The goal of the current study was to examine the utility of processing-based tasks for the assessment of language ability in bilingual children within the theoretical framework shaped by Baddeley's working memory model. The catalyst for this study was the realization that nearly all processing-based measures that have been considered by prior research are either direct measures of verbal short-term and working memory (e.g., non-word repetition and listening-span tasks) or rely strongly on verbal memory (e.g., word-learning tasks; e.g., Gathercole & Baddeley, 1990; Gathercole, Hitch, & Martin, 1997). In Baddeley's working memory model, performance on a verbal memory task is the outcome of an interplay between the degree to which the task taxes the Central Executive, and the degree to which the long-term linguistic knowledge can be recruited during the completion of a task.

Therefore, in the current study, we aimed to delineate the impact of both the Central Executive's involvement and long-term linguistic knowledge on processing-based task performance in bilingual and monolingual children. Because the most useful processing-based task would be unbiased against bilingual children who differ from their monolingual peers both in levels of language-specific knowledge and SES, our investigation focused on bilingual children who were characterized by precisely this profile.

Three types of processing-based measures were considered: measures of short-term memory, measures of working memory, and a novel word-learning task. We included the novel word-learning task because word learning has been suggested to index children's ability to learn and process language in a way that would be less biased than a standardized vocabulary test (Kan & Kohnert, 2008; Kapantzoglou, Restrepo, & Thompson, 2012; Restrepo, 1998; Wilkinson & Mazzitelli, 2003). The tasks varied in the degree to which they relied on extant linguistic knowledge, ranging from early-acquired familiar vocabulary used in the word-span and listening span tasks to unfamiliar novel words used in the non-word repetition task. The tasks also varied in the extent to which they relied on the Central Executive, from short-term memory tasks such as the word span (which do not involve the Central Executive) to working memory tasks such as the listening span (which do involve the Central Executive).

We first examined group differences across the different processing-based measures for bilingual vs. monolingual children. Of particular interest was examining whether group differences would fluctuate across processing-based tasks that differed with respect to long-term memory involvement. Baddeley's working memory model predicts that long-term language knowledge constrains the ability to maintain verbal information in the phonological loop. Since the bilingual children were characterized by lower levels of English knowledge than monolingual children, one hypothesis we considered was that group differences would be the strongest on processing-based tasks that involved the highest level of language knowledge (i.e., the listening-span task). At the same time, Baddeley's working memory model allocates an important function to the Central Executive, such that it is involved in performing working-memory but not short-term memory tasks. The outcome of this is that for working-memory tasks, the involvement of long-term linguistic knowledge may decrease while the role of the Central Executive may become more important. Another hypothesis we considered, therefore, was that group differences would be stronger for short-term memory tasks than for working-memory tasks, since bilingual children's lower levels of long-term English knowledge would have a more robust impact on short-term memory performance.

The ideal outcome of the group comparisons would be the identification of a processing-based task that would yield comparable levels of performance in the bilingual and the monolingual children. Beyond examining group differences on the processing-based measures, we also assessed the degree to which non-verbal IQ, SES, age, and linguistic knowledge (operationalized as children's performance on standardized vocabulary tests) were related to children's performance on processing-based measures. We conducted these analyses separately for the monolingual and the bilingual children, with the goal of identifying a processing-based task that would yield similar patterns of relationships with the predictor variables in the two groups. A task that would yield comparable levels of

performance in the bilingual and the monolingual children attained via similar predictive paths would be the best possible candidate for diagnostic purposes. This is because similar levels of performance, if achieved via different paths in different groups of typically-developing children, would be more sensitive to individual differences and thus less useful for distinguishing children with language impairment from those with typical language within each group.

2. Method

2.1 Participants

Bilingual and monolingual children were recruited through flyer distribution in local schools in Madison, WI. Children's developmental and educational history was obtained via primary caregiver interviews. Children with a language impairment, hearing impairment, learning disability, psychological/behavioral disorders, neurological impairments, or any other developmental disabilities were excluded from the present study. All children passed a bilateral hearing screening at 25dB. Participants included 36 English-speaking monolingual children (21 males, 15 females) and 46 English-Spanish bilingual children (17 males, 29 females) between the ages of 5 and 7 years old. Socioeconomic status (SES) was indexed in both groups by the primary caregiver's total number of years of education (following Ensminger & Fothergill, 2003; Entwisle & Astone, 1994; Hoff, 2003; Hoff, 2006; Kohn, 1963; etc.).

The monolingual children were all born in the U.S., attended English-speaking schools, and were exposed to only English in the home since birth. The bilingual group consisted of children who learned Spanish from birth, and whose age of English acquisition varied, with some children having acquired English from birth, and some children having acquired English at or after the age of three. As a group, the bilingual children began producing two-word phrases in English at 27.38 months ($SD = 13.67$) and in Spanish at 19.39 months ($SD = 8.55$). In a typical week, the group was exposed to English 42% of the time ($SD = 18.42$) and to Spanish 58% ($SD = 18.46$) of the time. Nearly half of the children (48%) attended a Spanish-English dual immersion program where they received at least 50% of their instruction in Spanish. With regard to the home language, the majority of the parents (59%) reported using Spanish in the home, 24% used English, and 17% used both English and Spanish. The majority of the bilingual children were of Hispanic background (28 of 46), 13 children had one parent who identified as Caucasian and one parent who identified as Hispanic, three children had both parents who identified as Caucasian, one child had one parent who identified as Hispanic and one who identified as Asian, and one child was adopted from Guatemala. See Table 1 for the demographic information for each group.

2.2 Materials

2.2.1 Standardized assessments—English receptive vocabulary was measured using the *Peabody Picture Vocabulary Test- 3rd Edition* (PPVT-III; Dunn & Dunn, 1997). English expressive vocabulary was measured using the Picture Vocabulary subtest of the *Woodcock-Johnson III Tests of Achievement* (Form A) (Woodcock, McGrew, & Mather, 2001). Spanish receptive vocabulary was measured using the *Test de Vocabulario en Imágenes Peabody*

(TVIP; Dunn, Padilla, Lugo, & Dunn, 1986), while Spanish expressive vocabulary was measured using the “Vocabulario sobre dibujos” subtest of the *Batería III Woodcock-Muñoz Pruebas de aprovechamiento* (Muñoz-Sandoval, Woodcock, McGrew, & Mather, 2005). The Visual Matrices subtest of the *Kaufman Brief Intelligence Test*, Second Edition (KBIT-2; Kaufman & Kaufman, 2004) was administered as a measure of non-verbal intelligence. All standardized test scores are available in Table 1 for both groups.

2.2.2 Short-term memory—Measures of short-term memory included the forward digit span, the word-span, and the non-word repetition task, all administered in English.

2.2.2.1 Memory for digits: A subtest from the *Comprehensive Test of Phonological Processing*- 1st Edition (CTOPP; Wagner, Torgesen, Rashotte, & Pearson, 1999), Memory for Digits, was administered. This is a forward digit span task that requires children to recall lists of digits increasing in length. Because names of digits are highly automatized (e.g., Gathercole & Adams, 1993), this task is characterized by minimal reliance on long-term linguistic knowledge.

2.2.2.2 Word span: The word span task requires children to recall lists of familiar words; it does therefore rely more significantly on long-term linguistic knowledge (Engle, Nations, & Cantor, 1990; Poirier & Saint-Aubin, 1995) than the forward digit span. In the current study, children heard lists of two, four, six, and eight words (all nouns) and were asked to recall the words in each list. Across all lists, the stimuli were matched for lexical frequency (based on the Brysbaert & New database, 2009) and concreteness (MRC Psycholinguistic Database). The age of acquisition norms from the MRC Psycholinguistic Database were used to ensure that all words were early-acquired ($M_{Age} = 2.32$ years). In addition to manipulating the list length, syllable-length of the words was manipulated. Twenty one-syllable words, 20 two-syllable words, and 20 three-syllable words were grouped into lists of each length. The stimuli were matched in phonotactic probability (calculated according to Vitevitch & Luce, 2004), and in phonological neighborhood size (calculated according to Marian, Bartolotti, Chabal, & Shook, 2012). The children were instructed to listen carefully and to recall as many words as possible in each list. The task was presented so that all children first heard one-syllable words in lists of each length, followed by two-syllable words and finally three-syllable words. The order of words in each list was randomized.

All responses were audio recorded and then transcribed by a research assistant off-line. Another coder re-transcribed 10% of the productions to ensure transcription reliability. Each response was coded as correct if the recalled word was on the target list, independent of order. Responses were marked as incorrect if the recalled words were duplications of already recalled words, additions of words not in the original list, or if a target word from the list was not recalled. Proportion correct scores were calculated for each list. Ten percent of the data were re-transcribed and re-coded with an inter-rater reliability of 98.7%.

2.2.2.3 Non-word repetition: The non-word repetition task requires children to repeat novel words. It therefore relies on phonological knowledge, but unlike the word-span task, does not tap long-term semantic knowledge (Baddeley, Gathercole, & Papagno, 1998; Edwards, Beckman, & Munson, 2004). In the current study, the non-word repetition subtest from the

CTOPP (Wagner, Torgesen, Rashotte, & Pearson, 1999) was used. The novel words in this task were based on English phonotactics.

2.2.3 Working memory—Measures of working memory included the backwards digit span and a listening span task, administered in English.

2.2.3.1 Numbers reversed: The backward digit span requires children to recall lists of digits in reverse order from that in which they were presented. In the current study we used the “Numbers Reversed” subtest from the *Woodcock Johnson-III – Test of Cognitive Abilities* (Woodcock, McGrew, & Mather, 2001).

2.2.3.2 Listening span: The listening span task requires children to listen to short sentences, judge the truthfulness of each sentence, and recall the last word of each sentence. The listening span task requires greater reliance on long-term linguistic knowledge than the backward digit span task since it involves processing of semantic and syntactic information. In the current study, an experimental *Listening Span* task, using stimuli from the Gaulin and Campbell (1994) Competing Language Processing Task, was administered. The stimuli included 42 short sentences (subject-verb-object; subject-verb-modifier; subject-auxiliary-main verb), which were grouped into two sets of sentence lists varying in length from one sentence to six sentences. The sentences were constructed using early-acquired vocabulary. Across sets, the sentences were controlled for length and difficulty level. Each sentence was designed so that it was a true or a false statement. The children were asked to listen to each sentence, to make a true/false decision about the sentence by producing “true/yes” or “false/no” out loud, and to memorize the last word in each sentence. Children were cued to recall the last word of each sentence, irrespective of the order in which the sentences were presented, once all of the sentences in a list were presented. The task was designed to continuously increase in difficulty level, so that shorter sentence sets were presented first, followed by longer sentence sets.

All responses were audio recorded and transcribed by a research assistant off-line. Only recall accuracy was used for analyses in the present paper. All words recalled from the set were considered correct. Incorrect responses were marked if the words were duplications of already recalled words, added words that were not from the target list, words that were not the final word in the sentence, words from previous sets, or if a target word was not recalled. Proportion correct was calculated for each list length, averaging across the two sets with the same sentence length. The inter-rater reliability was determined by double-coding 10% of the data, resulting in 99.0% inter-rater reliability.

2.2.4 Novel Word-Learning Task—A novel word-learning task where referent familiarity was manipulated was used to assess novel word learning. Two lists of eight novel words based on English phonotactics were selected from a set of novel words designed by Gupta et al. (2004). This database of novel words consists of stimuli controlled for phonological properties; they are grouped into sets that are matched on consonant onset and neighborhood density. For the present task, bi-syllabic novel words that followed CVCVC syllable structure and matched on length, stress pattern, and phonotactic probability were selected. Referent familiarity was manipulated so that children learned one list of words

paired with familiar referents (animals) and one list of words paired with unfamiliar referents (aliens). Pictures of familiar referents were selected from the International Picture naming Database (Székely et al., 2004) and pictures of the unfamiliar referents were selected from the Gupta et al. (2004) database.

Children saw one picture at a time and heard the corresponding novel word. The novel words were presented at a comfortable volume. Each word was presented twice prior to moving on to the next picture-word pair, and each word list was presented twice to each child, resulting in four presentations of each word during the learning phase. The pictures were presented in the middle of a computer screen on a white background and remained on the screen for 6 seconds. The order in which picture-word pairs were presented was randomized for each participant. In one session, children learned eight novel words paired with familiar referents and in another session children learned a new set of novel words paired with unfamiliar referents. The two sessions were at least one week apart. The order of condition (familiar vs. unfamiliar first) was counterbalanced across children. Further, the two lists of novel words were counterbalanced with regard to whether they were paired with familiar vs. unfamiliar referents. After the learning task, children completed a forced-choice recognition task. Children were presented with four pictures, of either animals or aliens, and heard one novel word. Children were instructed to choose the picture that they believed corresponded to the novel word that they heard.

2.3 Procedure

All auditory stimuli used for the word span task, listening span task, and the word learning task were recorded by a monolingual native English-speaking female from the Midwest. All the stimuli were recorded in a soundproof booth at a 20 kHz sampling rate and were normalized to 70dB amplitude using Praat (Boersma & Paul, 2001). The novel word learning tasks were always administered first but all other tasks were administered in random order during the testing sessions. The number of testing sessions varied from two to three. The standardized measures were scored in accordance with standardized rules described in each measure's manual. Standard scores were used in all of the analyses. Proficient English-Spanish bilingual research assistants who spoke both languages with native or near-native proficiency administered all Spanish measures.

2.4 Analyses

First, independent samples *t*-tests were conducted in order to compare the monolingual and bilingual groups on demographic characteristics and language skills. Second, a multivariate analysis of variance (MANOVA) was conducted for each construct (short term memory, working memory, and word learning) in order to assess whether there were group differences in performance on each task within each construct. Last, regression models were constructed for each task so that performance on short-term memory tasks, working memory tasks, and novel word learning tasks served as outcome variables and non-verbal intelligence, SES, age, and composite vocabulary scores served as predictor variables. Correlations among all the variables can be found in Supplementary Materials. Three models were constructed for each domain. Model 1 always consisted of non-verbal intelligence and SES, Model 2 included age to account for developmental effects, and Model

3 included a composite vocabulary knowledge score in order to assess the contribution of vocabulary knowledge to performance in each domain. For the monolingual group, only the English composite vocabulary measure was considered. For the bilingual group, after checking the contribution of English composite vocabulary, English composite vocabulary was removed and Spanish composite vocabulary was added into Model 3 to assess the contribution of Spanish vocabulary knowledge to performance in each domain. The composite vocabulary knowledge score was calculated by converting the standardized receptive and expressive vocabulary scores into z-scores, separately for monolinguals and for bilinguals, and taking an average of the two for each child. Separate regression models were constructed for monolinguals and for bilinguals.

3. Results

3.1 Group Comparisons

Independent samples *t*-tests revealed that the two groups did not differ in age or in non-verbal IQ, but did differ significantly on SES (years of primary caregivers' education), and both expressive and receptive English vocabulary skills. Monolingual children had parents with more years of education and outperformed bilingual children on the vocabulary assessments (Table 1).

Next, MANOVAs were run to assess group differences on the processing-based tasks. For the short-term memory tasks, the omnibus test revealed a significant difference between groups, Wilks's $\lambda = 0.83$, $F(3, 77) = 5.34$, $p < .05$, $\eta p^2 = .17$. Univariate tests revealed significant group difference in performance on the non-word repetition task ($F(1, 79) = 9.16$, $p < .05$, $\eta p^2 = .10$), memory for digits ($F(1, 79) = 14.92$, $p < .05$, $\eta p^2 = .16$), and on the word span task ($F(1, 79) = 9.27$, $p < .05$, $\eta p^2 = .11$) with the monolingual group outperforming the bilingual group on all three tasks of short-term memory. Refer to Figure 1 for a graphical representation of the groups' performance on the short-term memory tasks.

For the working memory tasks, the omnibus test did not reveal a significant difference between groups, Wilks's $\lambda = 0.95$, $F(2, 69) = 2.02$, $p = .14$, $\eta p^2 = .06$. However, when the results were plotted (see Figure 2), visual inspection of the data suggested higher levels of performance on the Numbers Reversed task for the monolingual group. We therefore ran a follow-up ANOVA for this task only, which revealed that the group difference on this task was marginally significant ($F(1, 70) = 3.78$, $p = .056$, $\eta p^2 = .05$).

For the novel word-learning task, the omnibus test did not reveal a significant difference between groups, Wilks's $\lambda = 0.95$, $F(2, 76) = 1.94$, $p = .15$, $\eta p^2 = .05$, suggesting similar levels of word-learning performance in the two groups of children, for both word-learning tasks. Refer to Figure 3 for a graphical representation of these results.

3.2 Monolingual Regression Analyses

3.2.1 Short-term memory

3.2.1.2 Non-word repetition: Model 1, containing children's non-verbal IQ ($\beta = .47$, $p < .01$) and SES ($\beta = .10$, $p = .55$), accounted for 22% ($F(2, 32) = 4.56$, $p < .05$) of the variance.

Age ($\beta = -.15, p = .36$) was added to form Model 2 and improved the model by a non-significant 2% ($p = .36$). Composite vocabulary ($\beta = .46, p < .05$) was added to form Model 3 and improved the model by a significant 21% ($p < .01$). Together, the four variables accounted for 45% ($F(4, 30) = 6.09, p < .01$) of the variability in children's performance on the non-word repetition subtest.

3.2.1.2 Memory for digits: Model 1 containing children's non-verbal IQ ($\beta = .35, p < .05$) and SES ($\beta = -.01, p = .94$), accounted for only 12% of the variance ($F(2, 33) = 2.34, p = .11$). Age ($\beta = .12, p = .47$) was added to form Model 2 and improved the model by a non-significant 2% ($p = .47$). Composite vocabulary ($\beta = .33, p < .05$) was added to form Model 3 and improved the model by a significant 10% ($p < .05$). Together, the four variables accounted for 24% ($F(4, 31) = 2.46, p = .06$) of the variability in children's performance on the memory for digits task.

3.2.1.3 Word span task: Model 1 containing children's non-verbal IQ ($\beta = .37, p < .05$) and SES ($\beta = .23, p = .17$) accounted for 15% of the variance in children's performance ($F(2, 33) = 2.98, p = .07$). Age ($\beta = .47, p < .01$) was added to form Model 2 and improved the model by a significant 22% ($p < .01$). Composite vocabulary ($\beta = .07, p = .62$) was added to form Model 3 and only improved the model fit by 1% ($p = .62$). Together, the four variables accounted for 38% ($F(4, 31) = 4.73, p < .01$) of the variance in children's performance on the word span task.

Together, these analyses suggest that non-verbal intelligence but not SES played a role in monolingual children's short-term memory performance. Age predicted performance on the word span task only. Vocabulary skills were predictive of short-term memory performance for the non-word repetition and the digit-span tasks, but not for the word-span task.

3.2.2 Working memory analyses

3.2.2.1 Numbers reversed: Model 1, containing children's non-verbal IQ ($\beta = .35, p < .05$) and SES ($\beta = -.01, p = .93$), accounted for 13% ($F(2, 33) = 2.42, p = .10$) of the variance observed in children's performance. Age ($\beta = -.20, p = .22$) was added to form Model 2 and improved the model by a non-significant 4% ($p = .22$). Composite vocabulary ($\beta = .20, p = .26$) was added to form Model 3 and improved the model by a non-significant 3% ($p = .26$). Together, the four variables accounted for 20% ($F(4, 31) = 1.97, p = .12$) of the variability in children's performance on the numbers reversed task.

3.2.2.2 Listening span: Model 1 containing children's non-verbal intelligence ($\beta = .51, p < .05$) and SES ($\beta = .02, p = .90$) accounted for 26% ($F(2, 29) = 5.04, p < .05$) of the variance in children's performance. Age ($\beta = .10, p = .53$) was added to form Model 2 and improved the model by a non-significant 1% ($p = .53$). Composite vocabulary ($\beta = .45, p < .05$) was added to form Model 3 and significantly improve the model by 20% ($p < .05$). Together, the four variables accounted for 46% ($F(4, 27) = 5.77, p < .05$) of the variance in children's performance on the listening span task.

Together, these analyses suggest that non-verbal intelligence but not SES or age played a role in monolingual children's working memory performance. Vocabulary skills were

predictive of working memory performance only for the Listening Span task, but not for the backward digit-span task.

3.2.3 Novel word-learning analyses

3.2.3.1 Familiar referent condition: Model 1 containing children's non-verbal intelligence ($\beta = .43, p < .05$) and SES ($\beta = -.06, p = .69$) accounted for 20% ($F(2, 32) = 4.04, p < .05$) of the variance in children's performance. Age ($\beta = .45, p < .01$) was added to form Model 2 and improved the model by a significant 20% ($p < .01$). Composite vocabulary ($\beta = .01, p = .93$) was added to form Model 3 but did not significantly improve the model fit ($p = .93$). Together, the four variables accounted for 40% ($F(4, 30) = 5.07, p < .01$) of the variance in children's learning of novel words paired with familiar referents.

3.2.3.2 Unfamiliar referent condition: Model 1 containing children's non-verbal intelligence ($\beta = .21, p = .25$) and SES ($\beta = -.06, p = .75$) accounted for 5% ($F(2, 33) = 0.86, p = .43$) of the variance in children's performance. Age ($\beta = .18, p = .30$) was added to form Model 2 and improved the model by a non-significant 3% ($p = .30$). Composite vocabulary ($\beta = .05, p = .77$) was added to form Model 3 but did not significantly improve the model fit ($p = .77$). Together, the four variables accounted for 8% ($F(4, 31) = 0.71, p = .59$) of the variance in children's learning of unfamiliar referents.

Together, these analyses suggest that non-verbal intelligence played a role in monolingual children's word-learning performance but only when novel words were paired with familiar referents. SES did not serve as a significant predictor of children's ability to learn novel words in either condition. Age predicted performance only when novel words were paired with familiar referents. Furthermore, vocabulary knowledge did not serve as a significant predictor of children's ability to learn novel words paired with familiar or unfamiliar referents. Please refer to Table 2 for a summary of results.

3.3 Bilingual Regression Analyses

3.3.1 Short-term memory

3.3.1.1 Non-word repetition: Model 1, containing children's non-verbal IQ ($\beta = .46, p < .01$) and SES ($\beta = .27, p < .05$), accounted for 35% ($F(2, 43) = 11.40, p < .001$) of the variance observed in children's performance. Age ($\beta = .01, p = .94$) was added to form Model 2 and improved the model by a non-significant 0.1% ($p = .94$). English composite vocabulary ($\beta = .40, p < .05$) was added to form Model 3 and significantly improved the model fit by 6% ($p < .05$). Together, the four variables accounted for 41% ($F(4, 41) = 7.10, p < .001$) of the variability in children's performance on the non-word repetition task. The addition of Spanish composite vocabulary ($\beta = .20, p = .13$) instead of English composite vocabulary did not yield a significant improvement over Model 2 containing non-verbal IQ, SES, and age.

3.3.1.2 Memory for digits: Model 1, containing non-verbal intelligence ($\beta = .31, p < .05$) and SES ($\beta = .42, p < .01$) accounted for 33% ($F(2, 43) = 10.77, p < .001$) of the variance in children's performance. Age ($\beta = -.06, p = .65$) was added to form Model 2 and improved the model by a non-significant 1% ($p = .65$). English composite vocabulary ($\beta = .51, p < .05$)

was added to form Model 3 and improved the model by a significant 10% ($p < .05$). Together, the four predictors accounted for 44% ($F(4, 41) = 8.02, p < .001$) of the variance in children's performance on the memory for digits task. The addition of Spanish composite vocabulary instead of English composite vocabulary did not improve the model ($\beta = .03, p = .84$).

3.3.1.3 Word span: Model 1, containing children's non-verbal intelligence ($\beta = .25, p = .08$) and SES ($\beta = .35, p < .05$) accounted for 23% of the variance in children's performance ($F(2, 43) = 6.31, p < .05$). Age ($\beta = .35, p < .05$) was added to form Model 2 and improved the model by a significant 12% ($p < .05$). Adding English composite vocabulary ($\beta = .81, p < .001$) to form Model 3 significantly improved the model fit by 25% ($p < .001$). Together, the four predictors accounted for 60% ($F(4, 41) = 15.52, p < .001$) of the variance in children's performance on the word span task. The addition of Spanish composite vocabulary instead of English composite vocabulary did not improve the model ($\beta = .09, p = .53$). Together, these analyses suggest that both non-verbal intelligence and SES played a role in bilingual children's short-term memory performance. Age predicted performance on the word span task only. Importantly, even after accounting for non-verbal IQ, SES, and age, English but not Spanish vocabulary skills were highly predictive of children's performance on all three short-term memory measures.

3.3.2 Working memory analyses

3.3.2.1 Numbers reversed: Model 1, containing children's non-verbal IQ ($\beta = .33, p < .01$) and SES ($\beta = .57, p < .001$), accounted for 53% ($F(2, 39) = 21.57, p < .001$) of the variance observed in children's performance. Age ($\beta = -.12, p = .31$) was added to form Model 2 and improved the model by a non-significant 1% ($p = .31$). English composite vocabulary ($\beta = .37, p < .05$) was added to form Model 3 and improved the model by a significant 5% ($p < .05$). Together, the four variables accounted for 59% ($F(4, 37) = 13.46, p < .001$) of variability in children's performance on the numbers reversed task. When Spanish ($\beta = .29, p < .05$) rather than English composite vocabulary was entered into Model 3, it accounted for a significant additional 8% ($p < .001$) of the variance when compared to Model 2.

3.3.2.3 Listening span: Model 1, containing children's non-verbal intelligence ($\beta = .25, p = .08$) and SES ($\beta = .40, p < .01$) accounted for 25% ($F(2, 41) = 6.99, p < .01$) of the variance in children's performance. Age ($\beta = .55, p < .001$) was added to form Model 2 and improved the model by a significant 30% ($p < .001$). English composite vocabulary ($\beta = .44, p < .05$) was added to form Model 3 and significantly improved the model fit by 9% ($p < .05$). Together, the four predictors accounted for 64% ($F(4, 39) = 17.14, p < .001$) of the variance in children's performance on the listening span task. When Spanish ($\beta = .22, p = .051$) rather than English composite vocabulary was entered into Model 3, it accounted for a marginally significant additional 4% ($p = .051$) of the variance when compared to Model 2. Together, these analyses suggest that both non-verbal intelligence and SES played an important role in bilingual children's working memory performance. Age only predicted performance on the listening span task. Notably, even after accounting for non-verbal IQ, SES, and age, English and Spanish vocabulary skills were predictive of working memory performance.

3.3.3 Novel word learning analyses

3.3.3.1 Familiar referent condition: Model 1, containing children's non-verbal intelligence ($\beta = .14, p = .38$) and SES ($\beta = .15, p = .35$) accounted for only 5% ($F(2, 41) = 1.08, p = .35$) of the variance in children's performance. Age ($\beta = .25, p = .11$) was added to form Model 2 and improved the model by a non-significant 6% ($p = .11$). English composite vocabulary ($\beta = .58, p < .05$) was added to form Model 3 and significantly improved the model fit by 13% ($p < .05$). Together, the four predictors accounted for 24% ($F(4, 39) = 3.01, p < .05$) of the variance in children's learning of familiar referents. The addition of Spanish composite vocabulary instead of English composite vocabulary did not improve the model ($\beta = .19, p = .26$).

3.3.3.2 Unfamiliar referents: Model 1, containing children's non-verbal intelligence ($\beta = -.01, p = .96$) and SES ($\beta = .15, p = .36$) accounted for 2% ($F(2, 42) = 0.45, p = .64$) of the variance in children's performance. Age ($\beta = -.23, p = .13$) was added to form Model 2 and improved the model fit by a non-significant 5% ($p = .13$). English composite vocabulary ($\beta = .18, p = .48$) was added to form Model 3 but only improved the model fit by a non-significant 1% ($p = .48$). Together, the four predictors accounted for 9% ($F(4, 40) = 0.94, p = .45$) of the variance in children's learning of novel words paired with unfamiliar referents. The addition of Spanish composite vocabulary instead of English composite vocabulary did not improve the model ($\beta = -.15, p = .35$).

Together, these analyses showed that non-verbal intelligence, SES, and age did not predict bilingual children's word-learning performance in either condition (familiar or unfamiliar referents). However, English vocabulary knowledge served as a significant predictor, but only when novel words were paired with familiar referents. Spanish vocabulary knowledge did not serve as a significant predictor of word-learning performance, in either condition. Please refer to Table 3 for a summary of results.

4. Discussion

The goal of the present work was to contribute to our understanding of bilingual children's performance on processing-based tasks by embedding the examination of processing-based tasks within a theoretical model of working memory. This enabled us to systematically assess the role of long-term linguistic knowledge (in English for the monolinguals and in both English and Spanish for the bilinguals) and the Central Executive's involvement in bilingual and monolingual children's performance on processing-based tasks. We found that monolinguals were more likely to outperform bilinguals on short-term than on working memory and word-learning tasks. We also found that for monolingual children, non-verbal IQ scores, but not SES or vocabulary skills, consistently contributed to processing-based performance. Conversely, for the bilingual children, both SES and English vocabulary skills, but not non-verbal IQ scores, were highly predictive of performance on processing-based tasks.

4.1 Between-Group Differences

Consistent with the literature which indicates that exposure to two languages is associated with persistent lags in children's acquisition of language-specific lexical knowledge (Fernández et al., 1992; Hoff et al., 2012; Marchman, Fernald, & Hurtado, 2010; Thordardottir et al., 2006), the bilingual children in the present study presented with significantly lower English vocabulary skills than the monolingual children. Furthermore, consistent with demographic data for Hispanic Spanish-English bilinguals in the United States (Camarota, 2012), the bilingual children in the present study were characterized by lower levels of SES than the monolingual children. Although these group differences between bilinguals and monolinguals are ecologically valid, they do pose a challenge to the analyses and to the interpretation of group differences in performance on experimental tasks. One approach is to statistically control for these differences when comparing the two groups (Field, 2009), and indeed prior studies comparing bilinguals and monolinguals have often co-varied out group differences in SES and vocabulary measures (e.g., Blom et al., 2014; Carlson & Meltzoff, 2008). However, there are strong reasons to not take the co-variance approach because lower levels of SES and vocabulary are an inherent characteristic of the population of interest (Miller & Chapman, 2001).

In the present study, the difference between bilingual and monolingual children in vocabulary skills *and* in SES was in fact a desired one – it yielded a sample of bilingual children that was representative of the broader population, and it enabled us to examine whether processing-based tasks can capture typical language functioning in a sample of bilingual children characterized by both lower levels of language-specific knowledge and lower SES. Previous work with monolingual children has shown that the use of processing-based tasks reduced assessment bias associated with lower SES (e.g., Campbell et al., 1997). The question for the present study, therefore, was whether discrepancies in both SES and vocabulary skills would impact bilingual children's performance on processing-based tasks. Such an approach is clinically useful because group differences between bilinguals and monolinguals in vocabulary skills and SES are precisely the factors that necessitate the development of processing-based measures in the first place.

In line with previous studies that have used short-term memory tasks to index processing-based performance in bilingual vs. monolingual children (Kohnert et al., 2006; Thorn & Gathercole, 1999; Windsor et al., 2010), the monolingual children in our study outperformed the bilingual children on all of the short-term memory tasks. However, this finding contrasts sharply with findings obtained in previous studies assessing *monolingual* minority and majority children with varying SES backgrounds. Prior studies that have assessed the utility of processing-based tasks for reducing bias against monolingual minority children from lower SES backgrounds did *not* find group differences on short-term memory measures (Campbell et al., 1997; Rodekohr & Haynes, 2001). Our findings indicate that short-term memory measures do not ameliorate assessment bias against *bilingual* children characterized both by lower levels of language-specific knowledge and by lower SES. Furthermore, group differences did not fluctuate across the three short-term memory tasks, indicating that performance on these tasks may not have been influenced by the degree to which the task relied on long-term linguistic knowledge. Since all three of the short-term memory tasks

involved stimuli with English-like phonology, they may have been highly similar in terms of the children's ability to rely on English phonological knowledge. Alternatively, it is possible that for bilingual, but not for monolingual children, performance on all short-term memory tasks may have drawn on language-specific knowledge, resulting in uniform group differences on these tasks. With respect to what these findings suggest regarding the utility of short-term memory tasks as a bias-free assessment measure of bilingual children's language skills, it appears that such utility is limited.

In contrast to short-term memory tasks, we did not observe significant group differences on the working memory tasks. This finding is especially notable in view of significant group differences in SES as well as English vocabulary knowledge. We attribute this result to the crucial difference between short-term memory and working memory tasks, in that performance on the working memory tasks relies on the Central Executive more than performance on the short-term memory tasks (Baddeley, 2003). Baddeley's working memory model posits that as operational demands of the task increase, the involvement of the Central Executive in task performance also increases (Baddeley & Hitch, 1974). At the same time, as the involvement of the Central Executive increases, the contribution of the long-term linguistic knowledge to task performance may decrease (Henry, 2011). As a result, the impact of language-specific knowledge on task performance may also decrease, resulting in less biased assessment. Therefore, based purely on group comparisons, it appears that working memory tasks are better suited than short-term memory tasks for reducing assessment bias in the context of bilingualism.

Finally, no group differences were observed on the novel word-learning task, in either of the two referent familiarity conditions. The existing literature on bilingual word learning is rather sparse, and it is not entirely clear whether word-learning tasks reduce the gap between bilingual and monolingual performance. In fact, while some studies have reported higher levels of word-learning performance in monolingual participants (Wilkinson & Mazzitelli, 2003), other studies have shown similar levels of word-learning performance in monolinguals and bilinguals (Kan & Sadagopan, 2014), and yet another set of studies has yielded bilingual advantages on word-learning and/or fast-mapping tasks (Kan et al., 2014; Kaushanskaya et al., 2014). Research with monolingual children has demonstrated that the ability to learn novel words is strongly associated with the child's existing language knowledge so that children with better vocabulary skills are better able to learn novel words (e.g., Ellis Weismer & Evans, 2002; Gray, 2003, 2004). In the present study, we manipulated referent familiarity in order to assess whether monolinguals and bilinguals would approach novel word learning differently depending on the degree to which the task involved prior lexical-semantic knowledge. Because we did not find differences either between conditions or groups, we conclude that performance on our version of the word-learning task was likely predicted more by verbal memory capacity and less by long-term linguistic knowledge.

Together, the results of the group comparisons suggest that the word learning and working-memory tasks render bilingual and monolingual performance more similar than short-term memory tasks. However, in order to substantiate the potential of these tasks to index language abilities of bilingual children, it is important to examine whether the predictors that underpin children's performance on these processing-based measures are similar for

monolingual and bilingual children. If superficially similar levels of performance by monolingual and bilingual children on the same task are attained via distinct predictive pathways, the clinical usefulness of such a task may be uncertain. For instance, if it were the case that SES was more related to bilingual children's performance on processing-based tasks than to monolingual children's performance, lower scores on such a task in the monolingual group, but not in the bilingual group, could be interpreted to indicate a possible language impairment.

4.2 Predictors of Processing-Based Performance in Bilingual and Monolingual Children

The general pattern of findings regarding the relationships between non-verbal IQ, SES, age, and vocabulary skills on the one hand, and English processing-based performance on the other hand suggests that, in monolingual children, performance on processing-based measures was predicted primarily by their cognitive skills (i.e., non-verbal IQ), whereas, in bilingual children, it was predicted primarily by their SES and English vocabulary knowledge. This was true for both the short-term memory tasks, where monolinguals tended to outperform bilinguals, and for working memory and word-learning tasks, where monolinguals and bilinguals tended to perform similarly. Another notable finding was that age contributed to both bilingual and monolingual children's performance on the word span task, with other processing-based measures showing minimal and variable sensitivity to age effects in the two groups.

The relationship between vocabulary skills and processing-based performance is of particular theoretical significance because the Working Memory model allocates an important role to long-term linguistic knowledge in supporting performance on verbal memory tasks. The only three tasks where vocabulary skills played a role for monolingual children were non-word repetition, memory for digits, and listening-span tasks. These relationships are not surprising, as prior studies with monolingual children have also found links between children's vocabulary knowledge and performance on non-word repetition (e.g., Coady & Evans, 2008; Gathercole & Adams, 1994; Gathercole, Service, Hitch, Adams, & Martin, 1999) and digit span tasks (e.g., Gathercole et al., 1997; Gathercole, Willis, Emslie, & Baddeley, 1992). Similarly, it is logical that performance on the listening-span task – arguably the most language-heavy task in our battery – would be predicted by children's language abilities. What is surprising, however, is that vocabulary skills were not associated with monolingual children's performance on the backward digit-span, word span, and the two word-learning tasks. It is possible that the lack of relationships observed between vocabulary skills and performance on the backward digit-span task is due to higher cognitive demands associated with this task (vis a vis the forward digit-span). As a result, children may have relied on their cognitive abilities for the completion of this working memory task more so than for its short-term-memory counterpart, leaving less variability to be accounted for by the language skills. What is more difficult to explain is the lack of relationships between monolingual children's performance on the word-span and the word-learning tasks and their vocabulary skills, as we would have expected the word-span and the word-learning tasks to rely on vocabulary knowledge the most of all the processing-based tasks.

The lack of a relationship between vocabulary scores and word-span performance in the monolingual group may be due to the nature of the words we have used in the word-span task. All the words were early-acquired, high-frequency, concrete nouns. Thus, it may be that the task was so simple in terms of language demands for the monolingual children that it did not require activation of long-term knowledge. However, the significant relationship between age and word-span performance would indicate that the word-span task was difficult enough to be sensitive to developmental effects in the monolingual group. Furthermore, this account does not explain why vocabulary skills did not contribute to monolingual children's performance on the word-learning tasks. We hypothesize that the lack of the relationships between word-learning tasks and vocabulary knowledge in the monolingual group was conditioned by the fact that the word-learning task may have strained the working memory system the most for this group, and thus loaded more heavily onto the cognitive capacity vs. the linguistic capacity. Once the role of non-verbal IQ in performance on this task was accounted for, the linguistic skills contributed little explanatory power to the variability in children's performance. However, this explanation must remain entirely speculative until future studies examine how (and whether) fluctuations in Central Executive's involvement influence the degree to which children's vocabulary skills contribute to their task performance.

In contrast to monolingual children, we found that English vocabulary skills were highly predictive of bilingual children's performance on nearly all processing-based tasks. Thus, unlike monolinguals, bilinguals were observed to rely on their English vocabulary skills even when performing the forward digit-span task, likely because arithmetic skills in bilingual children are strongly linked to language proficiency (Geary et al., 1993; Marsh & Maki, 1976; Wang et al., 2007) and because access to numbers in the second language is less automatized (Meuter & Allport, 1999; Philipp et al., 2007). Bilinguals also appeared to recruit their English vocabulary knowledge when learning new words, although this result only held for words that were paired with familiar referents. These findings indicate stronger reliance on language-specific vocabulary skills for performing processing-based tasks in bilingual children than in monolingual children. This relationship between processing-based task performance and English vocabulary skills did not vary by the degree to which the task relied on the Central Executive, or by the degree to which the task overlapped with English language knowledge. Because all of the processing-based tasks in the present study were administered in English, it is unclear whether bilingual children would recruit similar mechanisms as the monolingual children if the tasks were administered in their native language, Spanish. Interestingly, when bilingual children's Spanish rather than English vocabulary skills were considered (thus rendering the analyses more similar to those conducted with monolingual children), a very limited role of Spanish vocabulary skills in children's processing-based performance was observed. The only tasks that elicited reliance on Spanish vocabulary skills were the two working-memory tasks. One previous study demonstrated recruitment of the first language for solving mathematical problems in bilinguals (Wang et al., 2007). It is unclear why such a relationship would be observed for the backward, but not the forward, digit span task in the present study, unless one were to propose that when it comes to number-processing, native-language vocabulary skills predict performance only when the task taxes the Central Executive.

The stronger relationships between English vocabulary skills and processing-based performance in the bilingual vs. the monolingual group is likely due to greater variability in bilingual levels of performance, across all the measures. However, finding that non-verbal IQ was the biggest contributor to the monolingual group's processing performance, while SES and English vocabulary skills were the biggest contributors to the bilingual group's processing performance could also be interpreted to indicate that different factors (cognitive vs. experiential) contribute to children's performance on processing-based tasks depending on children's background. It is notable that the variables that distinguished the two groups (i.e., vocabulary and SES) were also the variables that were differentially involved in processing performance for the two groups. This poses some difficulty in interpreting the results of the regression analyses. That is, the differences in the relationships between background measures and performance on processing-based tasks across the two groups of children in this study may indeed reflect the difference between bilingual and monolingual children. However, they may also reflect differences between children with higher vs. lower language levels and/or higher vs. lower levels of SES. Because in the present study, bilingualism, lower levels of language skills, and lower SES went hand in hand, it is impossible to say with certainty whether the distinct patterns of relationships observed for bilinguals and monolinguals reflect the effect of bilingualism, or the effects of lower language skills and/or lower SES.

It is important to point out that group differences in language performance are not a necessary condition for yielding differences in the relationship between language performance and other outcome measures. For instance, Kaushanskaya, Blumenfeld, and Marian (2011) showed that bilingual and monolingual adults with similar levels of vocabulary knowledge and short-term memory nevertheless were characterized by different relationships between vocabulary and short-term memory. That is, in their study, a stronger relationship between vocabulary and short-term memory skills was found in bilinguals than in monolinguals despite highly comparable levels of vocabulary and short-term memory skills in the two groups. We therefore interpret the differences in the relationships observed between predictor variables and processing-based performance in the two groups as indexing the effects of bilingualism upon these relationships. Another consideration that supports our interpretation is that although the groups in our study did not differ significantly in IQ scores, the bilingual children were characterized by lower levels of IQ than their monolingual peers. Therefore, were it the case that the predictive relationships were always stronger in the group with weaker skills, we would expect IQ to be more strongly related to processing performance in bilinguals than in monolinguals. Instead, the relationship between IQ and performance on processing-based tasks was stronger in the monolingual group than in the bilingual group. Together, these considerations lead us to interpret the group differences in regression results as reflecting differences between bilinguals and monolinguals (rather than differences in language abilities and/or SES). However, future work would need to systematically approach these factors one by one in order to demonstrate this unequivocally.

4.3 Conclusions and Clinical Implications

The present findings showcase that not every processing-based measure succeeds in reducing bias between monolingual and bilingual children who differ in SES and English language skills. English-based short-term memory tasks appear to be biased toward favoring monolingual speakers as evidenced by the significant group differences on all three tasks of short-term memory. In contrast, we did not observe significant group differences on the working memory and the novel word-learning tasks, indicating that processing-based tasks that rely on the Central Executive may be more suitable for assessment purposes with bilingual populations than the tasks that tap only the storage capacity of the phonological loop. However, we also found that the variables that predict performance on these tasks differed across the two groups of children, such that SES and English vocabulary skills were associated with processing-based performance in the bilingual children more than in the monolingual children.

Our logic in examining the predictors of processing-based performance in the two groups was that tasks that are predicted by different variables in different groups of children would be more sensitive to individual differences and thus less useful in clinical practice. Had we not considered the predictors of processing-based performance, we would conclude that the listening-span and the word-learning tasks are promising, bias-free assessment measures that yield similar levels of performance in typically-developing children from different linguistic backgrounds. However, performance on the listening-span task was highly associated with SES in the bilingual group, while in the monolingual group the relationship between SES and listening-span performance was non-existent. This renders the suitability of this task for diagnostic purposes less useful than the equivalent levels of performance in the two groups would suggest. This is because lower-than-expected levels of listening-span performance in a monolingual child may reflect language impairment, whereas lower-than-expected levels of listening-span performance in a bilingual child may reflect a disadvantaged SES background.

Similar considerations may be applied to the word-learning task involving familiar referents. We found comparable levels of performance on this task in the two groups of children. However, while IQ was predictive of word-learning performance in monolingual children, English vocabulary skills were predictive of word-learning in bilingual children. Our interpretation of this result is that monolingual children drew on their cognitive skills while bilingual children drew on their language-specific skills when learning novel words. If general dynamics of word-learning are instantiated differently in typically-developing bilingual and monolingual children, then difficulties in word-learning within the two populations would need to be interpreted differently during a diagnostic process.

By this logic, the word-learning task that involves the use of unfamiliar referents is the *only* task on which bilingual and monolingual children not only performed similarly, but also appeared to rely on similar mechanisms. However, the suitability of this task for clinical purposes must be moderated by two considerations: First, the lack of group differences was likely driven by floor effects in the data, with both groups of children struggling on this task. Second, none of our predictor variables (SES, non-verbal IQ, age, or vocabulary skills) contributed to children's performance on this task, in either group. These considerations then

cause us to question what exactly this task measured. Reducing task difficulty and including other cognitive measures to examine in relation to word-learning performance (e.g., a measure of the Central Executive) would be necessary before any suggestions are made with regard to using this task in the assessment of bilingual children's language skills.

Of course, these considerations must remain speculative until performance on processing-based tasks is examined in bilingual and monolingual children with language impairment. If processing-based tasks are to be used in assessment, they must be accompanied by well-established bilingual assessment procedures, such as administration of standardized measures (when appropriate norms are available), child observation and language sampling procedures, a detailed history of children's language development and exposure, and a careful solicitation of parent concerns. Particular emphasis should be placed on children's proficiency levels in each language as current findings indicate that bilingual children rely on their long-term linguistic knowledge in English when completing processing-based tasks administered in English. In conclusion, we tentatively suggest that in a bilingual assessment, the processing-based tasks that rely more on the Central Executive and less on long-term knowledge may be most helpful.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The present project was supported by NIDCD Grants R03 DC010465 and R01 DC011750, NIH Diversity Supplement R03 DC0104565 and Training Grant T32 DC005359. The authors are grateful to members of the Language Acquisition and Bilingualism Lab for assistance with data collection and data coding. The authors are particularly indebted to all of the families who participated in the present study as well as the numerous schools who generously aided in participant recruitment.

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Paper Highlights

- Monolingual English and bilingual English-Spanish children were tested
- Children completed short-term memory, working memory, and novel word-learning tasks
- Monolinguals outperformed bilinguals on short-term memory tasks
- No group differences were observed for working memory or word-learning tasks
- Vocabulary was more predictive of bilingual than of monolingual performance

Figure 1. Bilingual and monolingual performance on short-term memory tasks

Note. Panel A demonstrates monolinguals outperforming bilinguals on both subtests of the CTOPP. Panel B demonstrates monolinguals outperforming bilinguals on all but the two-word list length on the Word Span task. Error bars indicate 1 standard error.

**Significant at $p < .001$

*Significant at $p < .05$

Figure 2. Bilingual and monolingual performance on working memory tasks

Note. Panel A demonstrates no group differences on the Numbers Reversed task. Panel B demonstrates that monolinguals outperformed bilinguals only at level-1 of the listening span. Error bars indicate 1 standard error.

**Significant at $p < .001$

Figure 3. Bilingual and monolingual performance on the word learning tasks

Note. No group differences on the novel word learning task. Error bars indicate 1 standard error.

Table 1

Demographic information and group comparisons

	Monolinguals	Bilinguals	<i>t</i> -test
N	36	46	
Age (years)	6.34 (0.84)	6.24 (0.76)	$t(80) = 0.54$
Non-verbal IQ	106.31 (14.52)	100.30 (11.50)	$t(80) = 2.09$
SES	18.89 (2.87)	15.80 (5.98)	$t(80) = 2.85^*$
English Receptive Vocab.	119.89 (14.11)	98.67 (21.15)	$t(80) = 5.18^*$
English Expressive Vocab.	107.72 (11.39)	90.61 (20.31)	$t(80) = 4.53^*$
Spanish Receptive Vocab.	--	97.93 (15.89)	--
Spanish Expressive Vocab.	--	76.26 (20.26)	--

* To account for multiple comparisons, p -value was divided by number of comparisons, yielding a criterion for significance of $p < .01$.

Table 2

Summary of Significant Predictors in the Monolingual Group

	Non-verbal IQ	SES	Age	English Vocabulary
Short-term Memory Tasks				
Non-word Repetition	✓	x	x	✓
Memory for Digits	✓	x	x	✓
Word Span	✓	x	✓	x
Working Memory Tasks				
Numbers Reversed	✓	x	x	x
Listening Span	✓	x	x	✓
Novel Word Learning Tasks				
Familiar Referents	✓	x	✓	x
Unfamiliar Referents	x	x	x	x

✓ Significant predictor

x Not a significant predictor

Table 3

Summary of Significant Predictors in the Bilingual Group

	Non-verbal IQ	SES	Age	English Vocabulary	Spanish Vocabulary
Short-term Memory Tasks					
Non-word Repetition	✓	✓	x	✓	x
Memory for Digits	✓	✓	x	✓	x
Word Span	x	✓	✓	✓	†
Working Memory Tasks					
Numbers Reversed	✓	✓	x	✓	✓
Listening Span	x	✓	✓	✓	†
Novel Word Learning Tasks					
Familiar Referents	x	x	x	✓	x
Unfamiliar Referents	x	x	x	x	x

✓ Significant predictor

x Not a significant predictor

† Marginally significant predictor