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The relationship between vocabulary and short-term memory measures in monolingual and bilingual speakers

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Abstract

Previous studies have indicated that bilingualism may influence the efficiency of lexical access in adults. The goals of this research were (1) to compare bilingual and monolingual adults on their native-language vocabulary performance, and (2) to examine the relationship between short-term memory skills and vocabulary performance in monolinguals and bilinguals. In Experiment 1, English-speaking monolingual adults and *simultaneous* English–Spanish bilingual adults were administered measures of receptive English vocabulary and of phonological short-term memory. In Experiment 2, monolingual adults were compared to *sequential* English–Spanish bilinguals, and were administered the same measures as in Experiment 1, as well as a measure of expressive English vocabulary. Analyses revealed comparable levels of performance on the vocabulary and the short-term memory measures in the monolingual and the bilingual groups across both experiments. There was a stronger effect of digit-span in the bilingual group than in the monolingual group, with high-span bilinguals outperforming low-span bilinguals on vocabulary measures. Findings indicate that bilingual speakers may rely on short-term memory resources to support word retrieval in their native language more than monolingual speakers.

Keywords

sequential bilinguals, short-term memory, simultaneous bilinguals, vocabulary

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Vocabulary skills form the foundation of linguistic and cognitive functioning, influencing morpho-syntactic ability (e.g., Bates, Bretherton, & Snyder, 1988; Carlisle & Nomanbhoy, 1993), reasoning skills (e.g., Booth, Waxman, & Huang, 2005; Golinkoff, Mervis, & Hirsh-Pasek, 1994; Nippold, Erskine, & Freed, 1988; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002), metalinguistic capacity (e.g., Bialystok, 1988; Galambos & Goldin-Meadow, 1990; Yelland, Pollard, & Mercuri, 1993), and literacy acquisition (e.g., Metsala & Walley, 1998; Nation & Snowling, 1998; Wise, Sevick, Morris, Lovett, & Wolf, 2007). Vocabulary skills are also impacted by bilingualism, because bilingual experience necessarily implies reduced lexical exposure to each language. It is not surprising that sequential bilinguals (who acquire their second language/L2 after acquiring their native language/L1), tested in their second language, score lower on vocabulary measures than their monolingual peers (e.g., Kohnert, Hernandez, & Bates, 1998; Roberts, Garcia, Desrochers, & Hernandez, 2002; Rosselli et al., 2000). What is perhaps more surprising is that a similar pattern of findings has been documented for sequential bilinguals who are tested in their native language (L1), and for simultaneous bilinguals (who acquire their two languages simultaneously from birth). For example, both sequential and simultaneous bilingual children tested in their L1 tend to score lower on vocabulary measures than their age-matched monolingual peers (e.g., Ben-Zeev, 1977; Paez & Rinaldi, 2006; Pearson, Fernandez, & Oller, 1993; Windsor & Kohnert, 2004). (Note that this finding does not apply to conceptual development, because when bilingual children's vocabulary is measured in both languages, bilingual children tend to perform on a par with monolingual children, e.g., Pearson et al., 1993).

Patterns of weakened vocabulary performance in each of the bilinguals' two languages have also been noted in adults, although the findings are less reliable than in children. Evidence for discrepancies between monolingual and bilingual performance was obtained in studies using picture-naming and semantic-fluency tasks that test the efficiency of lexical access (e.g., Bialystok, Craik, & Luk, 2008; Gollan, Montoya, & Werner, 2002). For example, English–Spanish sequential bilinguals who were more dominant in English showed reduced semantic fluency performance compared to monolingual speakers of English (e.g., Gollan et al., 2002), suggesting more effortful access to English words, perhaps as a result of knowing Spanish. Similarly, bilinguals tested in their native and more dominant language showed reduced picture-naming performance (Ivanova & Costa, 2008) and increased rates of tip-of-the-tongue (TOT) states (Michael & Gollan, 2004) compared to monolingual speakers. However, standardized vocabulary measures that test the latent level of vocabulary knowledge (rather than the efficiency of lexical access), have not always yielded monolingual advantages. Some studies found that bilinguals tested in their dominant language (English) demonstrated lower receptive and expressive vocabulary performance than their monolingual English-speaking peers (e.g., Bialystok et al., 2008; Portocarrero, Burright, & Donovick, 2007). Alternatively, other studies demonstrated comparable bilingual and monolingual performance on standardized vocabulary measures such as the Peabody Picture Vocabulary Test (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Blumenfeld & Marian, 2007; Kaushanskaya & Marian, 2009). Therefore, while there is a general consensus that exposure to two languages can influence bilinguals' vocabulary skills in the native and/or dominant language, it remains unclear whether these effects are similar for simultaneous and sequential bilinguals, and whether these discrepancies can be observed on *offline* vocabulary tasks that do not require speedy lexical access.

The present study addressed two goals. The first goal was to compare bilingual and monolingual performance on standardized measures of vocabulary knowledge. In Experiment 1, monolingual participants were contrasted with *simultaneous* bilinguals, while in Experiment 2, monolingual participants were contrasted with *sequential* bilinguals. In both experiments, we

were interested in testing whether bilinguals' performance in English, their native and dominant language would differ from monolinguals' performance. Our second goal was to examine whether differences in phonological short-term memory capacity would contribute to monolingual and bilingual performance patterns on vocabulary measures. Phonological short-term memory refers to one's ability to remember linguistic information for a brief period of time (e.g., Baddeley, 1986). A large body of literature links phonological short-term memory capacity to vocabulary acquisition and word learning in both children (e.g., Gathercole, 1995; Gathercole & Baddeley, 1990; Service, 1992; Service & Kohonen, 1995) and adults (e.g., Atkins & Baddeley, 1998; Baddeley, Papagno, & Vallar, 1988; Papagno & Vallar, 1992). Therefore, phonological short-term memory was the logical choice as a possible factor in bilingual and monolingual performance on vocabulary measures.

The role of short-term phonological memory in vocabulary performance

Phonological short-term memory capacity is an important predictor of vocabulary acquisition patterns in children and adolescents (e.g., Gathercole & Adams, 1993, 1994; Gathercole, Service, Hitch, Adams, & Martin, 1999), and word learning in children and adults (e.g., Gathercole, Hitch, Service, & Martin, 1997). With regards to vocabulary knowledge, a clear link between phonological short-term memory and vocabulary development has been established in children. For example, children's performance on the nonword repetition task (where one has to repeat nonwords) as well as on the digit-span task (where one has to repeat sequentially presented digits in the correct order) predicted children's performance on vocabulary tests, both concurrently and longitudinally (e.g., Gathercole et al., 1997; 1999; Gathercole, Willis, Emslie, & Baddeley, 1992). With regards to word learning, children's performance on the nonword repetition task predicted their ability to learn new words in their own language (e.g., Gathercole & Baddeley, 1990) as well as in a second language (e.g., Service, 1992; Service & Kohonen, 1995).

For adults, an analogous relationship between phonological short-term memory capacity and word learning has been observed. For example, adults' nonword repetition performance predicted their ability to learn pseudowords based on L1 phonotactics (e.g., Atkins & Baddeley, 1998; Service, Maury, & Luotoniemi, 2007), as well as to acquire novel words in a foreign language (e.g., Baddeley, Papagno, & Vallar, 1988; Cheung, 1996; Dufva & Voeten, 1999; Ellis & Beaton, 1993a; Speciale, Ellis, & Bywater, 2004). Similarly, Rosen and Engle (1997) showed that when subject to a high cognitive processing load, adults with high working memory spans performed better on a category fluency task than adults with low working memory spans. However, not every study found a link between phonological short-term memory and word learning in adults. For example, Service and Craik (1993) did not find a significant correlation between young adults' word-learning performance and their nonword repetition skills. Service and Craik (1993) proposed that young learners may rely on a highly efficient word-learning strategy that depends less on phonological memory. It is possible to extend this argument to vocabulary performance in adulthood, and to hypothesize that with maturation, the lexical system may settle into a relatively stable state, where words can be retrieved and recognized with high efficiency. Evidence for reorganization of the lexical system with maturation comes from studies showing that in middle childhood, the lexical system shifts to become more categorical (e.g., Corsale & Ornstein, 1980; Sheng, McGregor, & Marian, 2006), and that in adulthood, gains in language proficiency result in higher lexical co-activation levels (e.g., Blumenfeld & Marian, 2007) and more efficient lexical retrieval (e.g., Michael & Gollan, 2004). Presumably,

an efficient system would not need to rely on phonological memory resources to support lexical retrieval, and the link between phonological short-term memory and vocabulary would thus be diluted in adults. The question remains, however, whether reliance on phonological memory would be maintained in adults whose vocabulary skills are weaker, as appears to be the case with bilingual speakers.

While the hypothesis that the strength of the relationship between two sets of cognitive skills may vary with language status (monolingual vs. bilingual) has not been previously tested, there is support for this hypothesis in the language-disorders literature. For example, Robinson, Mervis, and Robinson (2003) demonstrated that phonological memory measures correlated strongly with performance on grammar tasks in children with Williams Syndrome, but not in typically developing children. Grammatical skills are particularly weak in children with Williams Syndrome. As a result, children with Williams Syndrome relied on their phonological memory skills in order to perform the grammar tasks, while typically developing children had no need to do so. Because bilinguals may experience more difficulty than monolinguals on vocabulary tasks, it is possible that the relationship between phonological short-term memory capacity and vocabulary performance will be stronger in bilinguals than in monolinguals.

The present study

Findings in the pediatric and adult domains indicate that knowledge of two languages may influence bilinguals' vocabulary performance. However, it is unclear whether dominant-language vocabulary performance is affected by bilingualism, and whether differences in bilingual acquisition histories (simultaneous vs. sequential bilingualism) bear on dominant-language vocabulary performance. The first goal of the present study was to examine bilingual speakers' performance on standardized tests of vocabulary knowledge in English, their native and more dominant language. In Experiment 1, we compared monolingual speakers to simultaneous English–Spanish bilinguals, and used the Peabody Picture Vocabulary Test-III (PPVT III: Dunn & Dunn, 1997) to measure participants' English receptive vocabulary. In Experiment 2, we compared monolingual speakers to sequential English–Spanish bilinguals who acquired Spanish later in life, and used both the PPVT-III and the Expressive Vocabulary Test (EVT: Williams, 1997) to extend Experiment 1 findings to a measure of expressive vocabulary.

Because phonological short-term memory capacity has been linked to lexical performance in previous work, the second goal of the present study was to examine the relationship between phonological short-term memory and vocabulary knowledge in monolingual and bilingual speakers. In both Experiment 1 and Experiment 2, the digit-span task was administered to participants to obtain a measure of their phonological short-term memory. The digit-span task was chosen in light of evidence demonstrating that the working memory system subsumes both memory for the order in which information is presented (the sequential component) and memory for the information itself (the representational component – e.g., Burgess & Hitch, 1999; Gupta, 2003; Page & Norris, 1998). It is the sequential component of working memory that appears to be tightly linked to lexical performance (Gupta, 2003; Majerus, Poncelat, Elsen, & Van der Linden, 2006; Majerus, Poncelat, Greffe, & Van der Linden, 2006), and the digit-span task indexes this sequential component of working memory (Majerus, Poncelat, Van der Linden, & Weekes, 2008). Previous work demonstrated stronger reliance on phonological memory during linguistic tasks in participants with weaker levels of language function. In the present study, we tested the hypothesis that the relationship between the digit-span task and the vocabulary measures would be stronger in bilinguals than in monolinguals.

Experiment 1: Relating digit-span performance to measures of receptive vocabulary in monolinguals and bilinguals

In Experiment 1, receptive vocabulary knowledge and phonological short-term memory abilities were examined in a group of native monolingual English speakers and a group of simultaneous English–Spanish bilinguals who had learned both English and Spanish early in life and were English-dominant. Because the bilingual group was dominant in English, and because both groups had received their education in the USA and were currently students at a major university in the USA, we predicted that bilingual and monolingual receptive vocabulary scores (as measured by the PPVT-III) would not differ. However, since bilinguals had consistently spent less time throughout their lives using English (due to Spanish exposure), we reasoned that English lexical representations would be less readily accessible. As a consequence, we predicted that bilinguals would rely more on phonological short-term memory during vocabulary retrieval than their monolingual peers, resulting in a stronger relationship between receptive vocabulary and digit-span performance in bilinguals than in monolinguals.

Experiment 1 method

Participants. Fifty-four participants were recruited for Experiment 1, including 24 English–Spanish bilinguals and 30 English-speaking monolinguals (see Table 1 for participant characteristics). Bilinguals and monolinguals were matched in terms of age and education levels, and all participants spoke English as their dominant language. Participants in the bilingual sample had acquired English and Spanish simultaneously, with a mean Spanish acquisition age of 1.7 years ($SE = 0.5$). Language proficiency, learning history, and current exposure data were obtained from all bilingual participants using the Language Experience and Proficiency Questionnaire (Marian, Blumenfeld, & Kaushanskaya, 2007). All English–Spanish bilinguals indicated English to be their dominant language, and reported speaking Spanish with a high degree of proficiency (on average 7.97, $SE = 0.26$, on a scale from zero to 10), and being exposed to Spanish on average 23% of the time ($SE = 3.0$) on a daily basis.

Procedure. All participants were administered standardized tests of receptive vocabulary in English (their dominant language) and of phonological short-term memory. The receptive vocabulary test

Table 1. Experiment 1: Monolingual and bilingual participant characteristics (*Means* and *SE* values)

	Monolinguals	English–Spanish bilinguals	*F* and *p* values
Age	21.40 (0.71)	22.13 (1.1)	$F(1, 52) = 0.75$, $p = 0.56$
Years of education	15.05 (0.53)	15.38 (0.58)	$F(1, 52) = 0.80$, $p = 0.68$
Spanish acquisition age	—	1.71 (0.48)	
Percentage of daily exposure to L2 (out of 100%)	—	22.88 (2.97)	
Self-rated L2 speaking proficiency (0–10 scale)	—	7.63 (0.28)	
Self-rated L2 understanding proficiency (0–10 scale)	—	8.67 (0.25)	
Self-rated L2 reading proficiency (0–10 scale)	—	7.63 (0.27)	

was the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997). On the PPVT-III, participants are required to match an auditory label to one of four pictures presented as choices. The phonological memory test was the digit-span sub-test of the Comprehensive Test of Phonological Processing (CTOPP: Wagner, Torgesen, & Rashotte, 1999). On the digit-span sub-test, participants are required to repeat strings of digits that increase from one to nine in the order they were presented.

Analyses. To examine the relationship between vocabulary retrieval and working memory abilities in bilinguals and monolinguals, three sets of analyses were conducted. *First*, to compare bilinguals' and monolinguals' performance on the vocabulary and working memory measures, between-group *t*-tests were conducted. *Second*, to examine the relationship between the vocabulary and working memory measures in each of the two groups, both correlations and between-group analyses were performed. PPVT-III scores and digit-span scores were entered into Pearson correlation analyses for the monolingual and the bilingual group. Next, participants were median-split into high-span and low-span sub-groups based on their digit-span scores and within-group and between-group analyses were conducted on vocabulary knowledge. *Third*, to confirm the role of short-term memory in vocabulary retrieval, both the monolingual and the bilingual groups were divided into high-vocabulary and low-vocabulary sub-groups based on their PPVT-III scores. Separate Pearson correlation analyses between the vocabulary and the digit-span measures were conducted for monolingual high-vocabulary and low-vocabulary sub-groups and for bilingual high-vocabulary and low-vocabulary sub-groups.

Experiment 1 results and discussion

Comparing bilinguals and monolinguals on vocabulary and digit-span measures. Independent-samples t-tests revealed similar performance on the PPVT-III for bilinguals ($M=79.8$, $SE=4.2$) and monolinguals ($M=81.8$, $SE=3.5$), $t\,(52)=0.37$, $p=0.72$, as well as similar performance on the digit-span task for bilinguals ($M=74.8$, $SE=4.8$) and monolinguals ($M=75.8$, $SE=3.9$), $t\,(52)=0.18$, $p=0.86$. These comparisons indicate that bilingualism did not reduce the level of dominant-language vocabulary and short-term memory performance found in monolinguals.

Relating digit-span and vocabulary performance in monolinguals and bilinguals

Pearson correlation analyses. Monolingual and bilingual participants' PPVT-III scores were correlated with their digit-span scores. Correlation analyses revealed that in monolingual English speakers, digit-span scores did not correlate with the PPVT-III ($r=0.35$, $p=0.1$). However, in bilingual English–Spanish speakers, digit-span scores correlated strongly and positively with PPVT-III scores ($r=0.65$, $p=0.001$).

High- vs. low-span analyses. In order to compare participants with high and low working memory spans on vocabulary knowledge, monolingual and bilingual participants were divided into high-span and low-span sub-groups based on their digit-span performance. The median-split procedure resulted in comparable sub-groups for bilinguals and monolinguals. For bilinguals, the low-span sub-group showed an average performance in the 57th percentile ($SE=6.17$), while the high-span group showed an average performance in the 92nd percentile ($SE=1.40$), $t\,(22)=5.5$, $p<.001$. For monolinguals, the low-span sub-group showed an average performance in the 60th percentile ($SE=5.23$) while the high-span group showed an average performance in the 92nd percentile ($SE=1.17$), $t\,(28)=5.9$, $p<.001$.

Univariate Analyses of Variance with digit-span (high vs. low) as the independent variable were conducted separately for bilingual and monolingual participants. For monolinguals, analyses of

variance did not reveal an effect of digit-span on PPVT-III performance, $F(1, 28) = 0.88$, $p = 0.36$, $\eta_p^2 = 0.03$. That is, participants in the high-span and low-span monolingual sub-groups did not differ in their vocabulary performance. Conversely, for bilinguals, analysis of variance revealed an effect of digit-span on PPTV-III performance, $F(1, 22) = 4.85$, $p = 0.038$, $\eta_p^2 = 0.18$. This finding suggests that bilinguals in the high-span group outperformed bilinguals in the low-span group on receptive vocabulary.

Relating working memory to vocabulary performance in high- and low-vocabulary participants. To examine whether participants with different vocabulary skills differed in how they recruited memory resources during vocabulary retrieval, participants in the monolingual and the bilingual groups were divided into high-vocabulary and low-vocabulary sub-groups based on their receptive vocabulary scores. In monolinguals, a median-split procedure based on PPVT-III scores yielded a high-receptive-vocabulary sub-group (*Mean Percentile* = 94.72, *SE* = 0.98) and a low-receptive-vocabulary sub-group (*Mean Percentile* = 68.87, *SE* = 5.00), $t(28) = 5.1$, $p < 0.001$. In bilinguals, the same procedure also yielded a high-receptive-vocabulary sub-group (*Mean Percentile* = 94.57, *SE* = 1.29) and a low-receptive vocabulary sub-group (*Mean Percentile* = 65.00, *SE* = 5.66), $t(22) = 5.1$, $p = 0.004$.

Pearson correlation analyses were conducted within each sub-group to examine the relationship between receptive vocabulary skills and digit-span. For monolinguals, the relationship between PPVT-III and digit-span scores was not significant for either the high-receptive-vocabulary group ($r = 0.05$; $p = 0.87$) or for the low-receptive-vocabulary group ($r = 0.17$; $p = 0.54$). Interestingly, for bilinguals, the relationship between PPVT-III scores and digit-span remained insignificant for the high-receptive-vocabulary group ($r = -0.052$; $p = 0.87$), but became positively correlated and highly significant for the low-receptive-vocabulary group ($r = 0.80$; $p = 0.002$). These findings suggest that, for bilinguals, the positive correlation between receptive vocabulary and working memory abilities was present only in low-performance individuals. It is possible that, due to reduced exposure to each of their languages, bilinguals with lower vocabularies have to work harder to retrieve words during auditory comprehension. Because of these additional task demands, low-vocabulary bilinguals may make increased use of memory resources during word comprehension.

In sum, findings in Experiment 1 confirmed the prediction of a stronger link between receptive vocabulary and phonological short-term memory in bilinguals compared to monolinguals. Moreover, follow-up analyses suggested that bilinguals with low vocabulary knowledge relied more on phonological short-term memory during vocabulary testing than bilinguals with high vocabulary knowledge. Together, these findings suggest that phonological short-term memory capacity may influence bilinguals' ability to retrieve words during comprehension. The goal of Experiment 2 was to extend these findings to late bilinguals, and to expressive vocabulary skills.

Experiment 2: Relating digit-span performance to measures of receptive and productive vocabulary in monolinguals and bilinguals

Results of Experiment 1 indicate that simultaneous (early) bilinguals, who learned both languages from an early age, when tested in their dominant language, do not demonstrate lower levels of receptive vocabulary knowledge than monolinguals. These findings are consistent with a number of other studies that have found similar levels of vocabulary performance in monolingual speakers and bilingual speakers tested in their native and dominant language (e.g., Bialystok et al., 2004; Blumenfeld & Marian, 2007; Kaushanskaya & Marian, 2009). However, Experiment 1 also showed that seemingly comparable levels of receptive vocabulary knowledge in simultaneous bilinguals

and monolinguals may be an outcome of different cognitive strategies in the two groups. Bilinguals, but not monolinguals, tend to rely on their phonological short-term memory in order to complete a word recognition task. The bilingual performance pattern appears to be driven by bilingual participants with relatively low receptive vocabulary skills. Conversely, monolinguals do not appear to rely on phonological short-term memory for word recognition, and this is the case for monolinguals with relatively high and relatively low receptive vocabulary skills. The goal of Experiment 2 was to examine whether similar patterns of results would be obtained with sequential (late) bilinguals, who were exposed to their L2 after having fully acquired their L1. We also aimed to replicate the findings of Experiment 1 for receptive vocabulary knowledge and to extend them to a measure of expressive vocabulary. Word recognition is a less taxing cognitive task than word production (e.g., De Groot & Keijzer, 2000; Ellis & Beaton, 1993b). Therefore, we expected an even stronger relationship between phonological short-term memory and performance on the expressive vocabulary task in bilinguals in Experiment 2.

Experiment 2 method

Participants. Sixty participants were recruited for Experiment 2: 30 sequential English–Spanish bilinguals and 30 English-speaking monolinguals. None of the participants tested in Experiment 2 took part in Experiment 1. Participant characteristics are presented in Table 2. The two groups were comparable in terms of age and education levels. All participants were native speakers of English, with participants in the bilingual group having acquired Spanish as a second language on average at 7.5 years of age ($SE = 1.4$). A comparison between bilingual participants in Experiment 1 and Experiment 2 showed that bilinguals in Experiment 2 acquired Spanish at a significantly later age than participants in Experiment 1 ($p < 0.01$). Language proficiency, learning history, and current exposure data were obtained from all bilingual participants using the Language Experience and Proficiency Questionnaire (Marian et al., 2007). Bilingual participants' learning history data (see Table 2) revealed that English–Spanish bilinguals spoke Spanish with a high degree of proficiency (on average, 7.5, $SE = 1.4$ on a scale from zero to 10), and were exposed to Spanish about 12% of the time ($SE = 14.1$) on a daily basis. All participants reported English to be their dominant language.

Table 2. Experiment 2: Monolingual and bilingual participant characteristics (*Means* and *SE* values)

	Monolinguals	English–Spanish bilinguals	*F* and *p* values
Age	22.64 (0.91)	22.12 (0.90)	$F(1, 59) = 0.17$, $p = 0.69$
Years of education	15.80 (0.46)	15.43 (0.46)	$F(1, 59) = 0.33$, $p = 0.57$
L2 acquisition age	—	7.39 (1.03)	
Percentage of daily exposure to L2 (out of 100%)	—	12.2 (14.1)	
Self-rated L2 speaking proficiency (1–10 scale)	—	7.29 (0.26)	
Self-rated L2 understanding proficiency (1–10 scale)	—	7.82 (0.22)	
Self-rated L2 reading proficiency (1–10 scale)	—	7.29 (0.29)	

Procedure. Standardized English vocabulary tests (receptive and expressive) were administered to all participants. As in Experiment 1, participants' receptive vocabulary knowledge was measured using the Peabody Picture Vocabulary Test-III (Dunn & Dunn, 1997), and their phonological short-term memory was measured using the digit-span sub-test of the Comprehensive Test of Phonological Processing (CTOPP: Wagner et al. 1999). In addition, participants' expressive vocabulary was measured using the Expressive Vocabulary Test (EVT: Williams, 1997). The EVT requires participants to produce a synonym to an auditory label while looking at the appropriate picture.

Analyses. Three sets of analyses were conducted. *First*, to compare bilingual and monolingual levels of performance on the vocabulary and the digit-span measures, between-group comparisons were performed. *Second*, to examine the relationship between the digit-span and the vocabulary measures across the two groups, both correlation and group-based analyses were performed. Pearson correlation analyses were conducted where the digit-span scores were correlated with the PPVT-III and the EVT scores for the monolingual and the bilingual group. Between-group comparisons were conducted where participants were median-split into the high-span and the low-span sub-groups based on their digit-span scores. *Third*, to substantiate the role of phonological memory in vocabulary retrieval, both the monolingual and the bilingual groups were divided into a high-vocabulary and a low-vocabulary sub-group based on their PPVT-III and EVT scores. Separate Pearson correlation analyses between the vocabulary and the digit-span measures were conducted for monolingual high-vocabulary and low-vocabulary sub-groups and for bilingual high-vocabulary and low-vocabulary sub-groups.

Experiment 2 results and discussion

Comparing bilinguals and monolinguals on vocabulary and digit-span measures. Independent-samples *t*-tests revealed comparable performance levels across monolinguals and bilinguals on the PPVT-III, $t\ (59)=0.78$, $p=0.44$, the EVT, $t\ (59)=1.65$, $p=0.10$, and the digit-span task, $t\ (59)=0.14$, $p=0.89$ (see Table 3). These comparisons indicate that bilingualism did not reduce or increase native-language vocabulary and working memory performance in sequential bilinguals.

Relating digit-span and vocabulary performance in monolinguals and bilinguals

Pearson correlation analyses. Monolingual and bilingual participants' PPVT-III and EVT data were correlated with the digit-span data (see Table 4). Correlation analyses revealed that in monolingual English speakers, digit-span scores did not correlate with either the PPVT-III ($p=0.29$) or the EVT scores ($p=0.19$). Conversely, in bilingual English–Spanish speakers, digit-span scores correlated strongly and positively with both the PPVT-III data ($p<0.001$) and the EVT data ($p<0.001$).

Table 3. Experiment 2: Monolingual and bilingual performance on vocabulary and phonological short-term memory measures (*Means* and *SE* values)

	Monolinguals	English–Spanish bilinguals
PPVT-III (percentile)	86.36 (2.92)	83.08 (2.93)
EVT (percentile)	91.57 (3.74)	82.90 (3.68)
Digit-span (percentile)	75.82 (3.78)	75.07 (3.71)

Table 4. Experiment 2: Correlations between vocabulary and phonological short-term memory measures in monolingual and bilingual participants

	Digit-span	
	Monolinguals	English–Spanish bilinguals
PPVT-III	$r = 0.21$	$r = 0.61$*
EVT	$r = 0.25$	$r = 0.70$*

*$p < 0.001$

Table 5. Experiment 2: Between-group comparisons for high-span and low-span monolingual and bilingual participants (*Means* and *SE* values)

	High-span monolinguals	Low-span monolinguals
PPVT-III (percentile)	88.60 (2.86)	83.77 (3.07)
EVT (percentile)	94.79 (3.15)	87.85 (3.38)
	High-span bilinguals	Low-span bilinguals
PPVT-III (percentile)	90.59 (4.39)	73.85 (4.87)
EVT (percentile)	94.96 (5.31)	68.07 (5.89)

High- vs. low-span analyses. Participants in the monolingual and the bilingual group were divided into a high-span and a low-span sub-group based on their digit-span performance. In both groups, the median-split procedure resulted in comparable sub-groups. For monolingual speakers, the low-span sub-group performed on average in the 61st percentile ($SE = 4.68$) while the high-span group performed on average in the 89th percentile ($SE = 1.35$). For bilingual speakers, the low-span sub-group performed on average in the 56th percentile ($SE = 4.88$), while the high-span group performed on average in the 90th percentile ($SE = 1.27$).

Univariate Analyses of Variance with digit-span (high vs. low) as the independent variable were conducted separately for monolingual and bilingual participants. For monolinguals, ANOVAs did not reveal an effect of digit-span for performance on either the PPVT-III ($F(1, 29) = 1.32$, $p = 0.26$) or the EVT ($F(1, 29) = 2.26$, $p = 0.15$). That is, high-span and low-span monolingual sub-groups did not differ in their vocabulary scores. Conversely, for bilinguals, Univariate ANOVAs yielded a significant effect of digit-span on both the PPVT-III performance ($F(1, 29) = 6.52$, $p < 0.01$, $\eta_p^2 = 0.19$) and the EVT performance ($F(1, 29) = 11.52$, $p < 0.01$, $\eta_p^2 = 0.30$). Bilinguals in the high-span group outperformed bilinguals in the low-span group on both the receptive and expressive vocabulary measures (see Table 5).

Relating short-term memory to vocabulary performance in high- and low-vocabulary participants. Participants in the monolingual and the bilingual groups were divided into a high-vocabulary and a low-vocabulary sub-group based on their receptive and expressive vocabulary scores. In monolinguals, a median-split procedure based on PPVT-III scores yielded a high-receptive-vocabulary sub-group (*Mean Percentile* = 94.62, $SE = 1.02$) and a low-receptive-vocabulary sub-group (*Mean Percentile* = 79.20, $SE = 2.71$). In bilinguals, the same procedure also yielded a high-receptive-vocabulary sub-group (*Mean Percentile* = 97.36, $SE = 0.53$) and a low-receptive-vocabulary sub-group (*Mean Percentile* = 67.79, $SE = 4.66$). Pearson correlation analyses within

each sub-group were conducted to examine the relationship between receptive vocabulary skills and the digit-span scores in participants with relatively low receptive vocabulary skills and in participants with relatively high receptive vocabulary skills. For monolinguals, the relationship between PPVT-III scores and the digit-span was not significant for either the high-receptive-vocabulary group ($p = 0.45$) or the low-receptive-vocabulary group ($p = 0.44$). For bilinguals, the relationship between PPVT-III and digit-span scores approached significance in the low-receptive-vocabulary group ($r = 0.44$, $p = 0.12$), but was not significant for the high-receptive-vocabulary group ($p = 0.31$).

To examine the relationship between expressive vocabulary and digit-span measures, a median-split procedure based on EVT scores was implemented. For monolinguals, a median-split based on the EVT scores yielded a high-expressive-vocabulary sub-group (*Mean Percentile* = 98.45, *SE* = 0.29) and a low-expressive-vocabulary sub-group (*Mean Percentile* = 85.60, *SE* = 3.80). In bilinguals, the same procedure also yielded a high-expressive-vocabulary sub-group (*Mean Percentile* = 98.83, *SE* = 0.37) and a low-expressive-vocabulary sub-group (*Mean Percentile* = 63.31, *SE* = 7.28). Pearson correlation analyses within each sub-group were conducted to examine the relationship between expressive vocabulary skills and the digit-span in participants with relatively low expressive vocabulary skills and in participants with relatively high expressive vocabulary skills. For monolinguals, the relationship between EVT scores and the digit-span was not significant for the high-expressive-vocabulary group ($p = 0.97$), but was highly significant for the low-expressive-vocabulary group ($r = 0.79$, $p < 0.001$). For bilinguals, the relationship between EVT scores and the digit-span was significant for both the high-expressive-vocabulary group ($r = 0.53$, $p < 0.05$) and for the low-expressive-vocabulary group ($r = 0.62$, $p < 0.01$).

Two patterns of findings are noteworthy. First, the digit-span measure appears to share a stronger relationship with the EVT – the expressive vocabulary measure, than with the PPVT-III – the receptive vocabulary measure. This is not surprising, since the short-term memory load is higher during expressive vocabulary testing (where one must retrieve a synonym for the heard target word) than during receptive vocabulary testing (where one must only map the heard target word to the appropriate picture). Second, it appears that phonological short-term memory supports vocabulary access only in participants who experience difficulties with lexical retrieval. For monolinguals, these are participants with relatively low expressive vocabulary skills. For bilinguals, these are participants with both relatively low and relatively high expressive vocabulary skills.

General discussion

In two experiments, we examined vocabulary and phonological short-term memory performance in bilinguals' native and dominant language. In both Experiment 1 and Experiment 2, English-speaking monolinguals and English-dominant bilinguals demonstrated comparable levels of vocabulary knowledge, as tested through standardized measures of receptive and expressive vocabulary. Moreover, bilinguals and monolinguals demonstrated equal levels of performance on the phonological short-term memory task, also administered in English. Group differences were revealed only when the relationship between vocabulary and phonological short-term memory measures was examined. Both correlation and between-group analyses indicated that vocabulary retrieval and phonological short-term memory skills were strongly linked in bilinguals, but not in monolinguals. Findings were replicated across experiments, and indicate that knowledge of two languages carries similar consequences for dominant-language vocabulary performance in simultaneous (early) bilinguals (Experiment 1) and sequential (late) bilinguals (Experiment 2). Convergent results, despite these bilingual group differences, suggest that the findings are robust

and consistent across a range of language history profiles, and are thus likely to generalize to a wide range of bilinguals.

The finding that bilinguals and monolinguals demonstrated comparable dominant-language vocabulary performance on standardized measures is consistent with previous reports (e.g., Bialystok et al., 2004; Blumenfeld & Marian, 2007; Kaushanskaya & Marian, 2009). However, it is still unclear why reports of both equal and reduced levels of vocabulary performance have been noted in the literature for seemingly similar groups of bilingual speakers. One possibility is that comparable levels of vocabulary performance are observed for bilinguals and monolinguals when lexical retrieval is measured without the imposition of time constraints (as is the case for standardized tests like the PPVT-III and the EVT). Conversely, reduced levels of vocabulary performance are observed for bilinguals compared to monolinguals when lexical retrieval is measured via time-limited tasks (as is the case for semantic fluency tasks, e.g., Gollan et al., 2002) or via speed of retrieval (as is the case for picture naming tasks, e.g., Ivanova & Costa, 2008). That is, bilinguals may be slower to access words in their dominant language than monolinguals, but be just as accurate if given sufficient time. It is also clear that bilingual lexical performance is highly sensitive to the bilinguals' linguistic background. Performance shifts with increases in language proficiency have been documented for bilinguals' lexical performance (e.g., Daller, van Hout, & Treffers-Daller, 2003; Kroll & Stewart, 1994; Treffers-Daller, 2009) and bilinguals' working memory skills (e.g., Service, Simola, Metsanheimo, & Maury, 2002). It is therefore possible that discrepancies between studies that do and do not find differences between bilingual and monolingual vocabulary performance are simply a matter of cross-study fluctuations associated with bilinguals' language histories. Since bilinguals in our study were dominant in English, their vocabulary performance was on a par with that of their monolingual peers.

While our study did not find evidence of reduced lexical performance in bilinguals, the results suggested that seemingly equal levels of vocabulary performance in bilinguals and monolinguals may have been attained via different cognitive pathways in the two groups. In both Experiment 1 and Experiment 2, bilinguals' (but not monolinguals') performance on the receptive vocabulary task was associated with performance on the phonological memory task. Correlational analyses are necessarily non-directional, and only suggest a link between phonological short-term memory and vocabulary performance. However, the second-pass between-group comparisons where participants were divided into groups based on their phonological-memory performance enable us to posit a directional, causal link between phonological short-term memory capacity (as indexed by performance on the digit-span task) and vocabulary retrieval (as indexed by the PPVT-III and the EVT). Dividing the monolingual and the bilingual group into sub-groups according to the digit-span scores yielded highly comparable sub-groups with regards to demographic and language-experience characteristics. For instance, in Experiment 2, the split of bilingual participants into a high-digit-span and a low-digit-span bilingual subgroup yielded two bilingual subgroups that did not differ in any demographic variables (including age, years of education, age of L2 acquisition, or ratings of Spanish proficiency). This procedure minimized the possibility that differences between phonological short-term memory sub-groups in vocabulary performance would be mediated by extraneous variables. Therefore, we interpret the finding of a more robust link between phonological short-term memory and vocabulary performance in bilinguals compared to monolinguals as indicating a stronger reliance on phonological short-term memory skills for vocabulary retrieval in bilinguals. A relationship between success of vocabulary retrieval (given ample time) and working memory skills indicates that even during 'off-line' tasks that probe for representations rather than processes, performance may in part be predicted by processing capacity (i.e., working memory skill). These findings may have implications for language assessment in bilingual

populations, in that even though no monolingual/bilingual differences may be apparent for off-line measures, cognitive processes that underlie performance on such measures may differ across monolinguals and bilinguals.

Our interpretation of the findings is further confirmed by the analyses that examined the relationship between phonological short-term memory and vocabulary knowledge separately for bilinguals with high and low vocabulary scores. In Experiment 1, these analyses revealed that the relationship between phonological memory and receptive vocabulary was strong in the low-receptive-vocabulary bilingual group, but was not significant in the high-receptive-vocabulary bilingual group. The same analysis in monolinguals did not reveal differences between the high and low vocabulary groups with regards to their reliance on phonological memory skills. In Experiment 2, a similar pattern of findings was obtained for the receptive vocabulary task, although here, the relationship between phonological short-term memory and PPVT-III scores in the low-receptive-vocabulary bilingual group failed to reach significance. It should be noted, however, that the correlation between PPVT-III and digit-span performance was the strongest in this group, and was much weaker for the bilingual group with high receptive vocabulary skills, or for the two monolingual sub-groups. Both Experiment 1 and Experiment 2 therefore suggest that the relationship between phonological short-term memory and vocabulary performance is found primarily in bilinguals with relatively low receptive vocabulary skills. Monolinguals, on the other hand, did not rely on phonological short-term memory resources for completion of the receptive vocabulary test, independent of their vocabulary skills.

Experiment 2 also showed that high-span and low-span bilinguals differed with respect to their performance on the EVT, while high-span and low-span monolinguals did not. An especially interesting finding was revealed when high-expressive-vocabulary and low-expressive-vocabulary sub-groups were created within the monolingual and the bilingual sample. In both bilingual sub-groups, there was a strong relationship between phonological short-term memory and expressive vocabulary performance, indicating that all bilinguals relied on phonological memory resources for lexical retrieval. In monolinguals, however, a relationship between phonological memory and expressive vocabulary performance was found only in the sub-group with relatively low expressive vocabulary scores. Thus, bilinguals with high and low expressive vocabulary skills, as well as monolinguals with low expressive vocabulary skills, relied on phonological memory resources during the lexical-retrieval task, while monolinguals with relatively high expressive vocabulary skills did not rely on phonological memory resources.

This pattern of findings indicates that the mechanisms of lexical functioning are the same in monolingual and bilingual speakers tested in their dominant language, but that the recruitment of these mechanisms differs for monolinguals and bilinguals. The contexts in which monolingual and bilingual individuals recruited phonological short-term memory resources in Experiments 1 and 2 are summarized in Figure 1. Emerging patterns suggest that the extent of phonological memory recruitment may depend on two dimensions of task difficulty. First, the demands of the lexical task dictate the degree of short-term memory involvement. While the receptive vocabulary task (PPVT-III) requires one to hold auditory information in memory until one can identify the correct picture match, the expressive vocabulary task (EVT) requires one to hold auditory information in memory until one can identify and produce synonyms. Since the time required to identify a picture is shorter than the time required to identify and produce a synonym, phonological memory demands are likely higher for the EVT than for the PPVT-III. This difference between tests is reflected in correlation patterns, with more consistent correlations between phonological memory and vocabulary identified for the EVT than for the PPVT-III.

	Task difficulty	
Group	Receptive vocabulary (PPVT-III)	Expressive vocabulary (EVT)
Monolingual, high vocabulary	—	—
Monolingual, low vocabulary	—	✓
Bilingual, high vocabulary	—	✓
Bilingual, low vocabulary	✓	✓

Figure 1. Schematic overview of groups where significant correlations between vocabulary and working memory performance were identified (with check-marks denoting significant correlations and hyphens denoting correlations that failed to reach significance)

The second dimension of task difficulty identified in Experiments 1 and 2 is that of language status. Language status can refer to the number of languages spoken (i.e., monolingual vs. bilingual speakers), as well as to ability levels within each language (i.e., high vs. low vocabulary skills). As a result of operating within two languages, bilinguals use each language less than monolingual speakers use their single language (e.g., Gollan et al., 2002) and may experience higher levels of lexical competition than monolingual speakers (e.g., Bialystok, 2009; Green, 1986, 1998). This can potentially lead to weaker lexical representations and lower activation levels within each of the bilinguals' two lexicons. Lower within-language activation levels and higher levels of lexical competition may in turn lead to longer lexical retrieval times for bilinguals as compared to monolinguals (e.g. Ivanova & Costa, 2008). Longer retrieval times may impose increased demands on phonological memory. In the current study, bilinguals consistently showed stronger associations between vocabulary performance and phonological short-term memory than did monolinguals. In addition, the argument of weaker representations can also be made for individuals with lower vocabulary knowledge (independent of bilingual status). As a consequence, a three-level preliminary hierarchy emerges, where individuals who are likely to rely more heavily on short-term memory resources during vocabulary retrieval can be localized to one of three levels of performance (Level 1: bilingual-low-vocabulary; Level 2: bilingual-high-vocabulary and monolingual-low-vocabulary; Level 3: monolingual-high-vocabulary). It is important to reiterate that no monolingual/bilingual vocabulary performance differences were identified in Experiments 1 and 2. Therefore, this hierarchy does not reflect differences in performance, but rather differences in the need to recruit phonological memory resources to scaffold vocabulary retrieval.

In conclusion, the current study found that simultaneous and sequential bilinguals tested using standardized vocabulary measures in their dominant language demonstrated vocabulary skills that were similar to their monolingual peers. However, the seemingly similar vocabulary levels appear to be attained via a greater reliance on phonological short-term memory resources in bilingual speakers. This suggests that the process of vocabulary retrieval is more effortful for bilinguals, but that off-line measures of vocabulary knowledge do not necessarily capture this effort.

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