Working Memory Capacity: Is There a Bilingual Advantage?

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Abstract

Previous studies suggest that bilinguals have certain executive function advantages over monolinguals. However, few studies have examined specific working memory (WM) differences between monolinguals and bilinguals using complex span tasks. In the current study, 52 bilingual and 53 monolingual speakers were administered simple and complex WM span tasks, including a backward digit span task, standard operation span tasks (Turner & Engle, 1989), and a nonverbal symmetry span task (Unsworth et al., 2005). Working memory performance was a strong predictor of performance on other WM tasks whereas bilingual status was not. Thus, the present study did not find evidence of a bilingual advantage in WM capacity.

Keywords: bilingualism, working memory, executive function

Working Memory Capacity: Is There a Bilingual Advantage?

Recent studies suggest that bilingual speakers have a cognitive advantage over monolingual speakers. Relative to monolingual speakers, bilingual speakers have shown better performance on tasks that require inhibiting irrelevant information. For example, Bialystok, Craik, & Ryan (2006, see also Bialystok & Viswanathan, 2009) found that bilinguals had faster response times than monolinguals during an antisaccade task, in which participants must inhibit the prepotent response to look towards a flashing stimulus. Similar bilingual advantages have been observed for other inhibition tasks, including the Simon task (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004), the Flanker task (Emmorey, Luk, Pyers, & Bialystok, 2008), and the Stroop task (e.g., Bialystok, Craik, & Luk, 2008). Bilingual advantages have also been found in task switching (e.g., Bialystok & Martin, 2004; Prior & Gollan, 2011) and updating/monitoring tasks (e.g., Bialystok, Craik, & Ruocco, 2006). The present study was designed to assess whether previously reported bilingual advantages extend to performance on complex working memory tasks.

The bilingual advantage in inhibitory, switching, and updating tasks may arise from the continuous selection and processing of lexical information in two languages. Bilingual models of lexical access assume that a concept automatically activates lexical representations in both languages (e.g., Dijkstra & Van Heuven, 1998, 2002). Several studies support the assertion that lexical items in both languages are active in bilinguals, regardless of the language required for the given task (e.g., De Groot, Delmaar, & Lupker, 2000; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998). For example, if a Spanish-English bilingual speaker thinks about the concept of a dog, the lexical representations for “perro” and “dog” will become active. A conflict arises because the person cannot simultaneously produce both items, and the speaker must select the appropriate word for the given context. The Inhibitory Control Model and Adaptive Control Hypothesis (Green, 1998; Green & Abutalebi, 2013) assume that the bilingual executive system will inhibit the task-irrelevant language. This constant management of the two languages leads to a bilingual advantage in inhibitory control.

In a recent review, Hilchey and Klein (2011) examined studies investigating inhibitory control advantages in bilinguals. The experimental tasks included the Simon task, the Flanker task, and the spatial Stroop task. In all tasks, targets were congruent or incongruent with the response and the additional response time to incongruent trials relative to congruent trials reflected an interference cost. Although Hilchey and Klein did not find evidence supporting superior inhibitory control in bilinguals, they found bilinguals were faster than monolinguals on both congruent and incongruent trials. They proposed that bilinguals have "advantages across a broad range of tasks in which the need for executive control is most pressing" (p. 655).

Recent neuroimaging results have also been used as evidence of a bilingual executive function advantage. The dorsolateral prefrontal cortex, an area associated with executive function abilities (e.g., D'Esposito, et al., 1995; Kane & Engle, 2002), is reported to be more active or enhanced in bilinguals compared to monolinguals (e.g., Hernandez, Martinez, & Kohnert, 2000; Holtzheimer, Fawaz, Wilson, & Avery, 2005; Mechelli, et al., 2004; Rodriguez-Fornells, et al., 2005). However, neural differences between bilinguals and monolinguals are not consistently associated with behavioral differences (e.g., Bialystok et al., 2005; Kousaie & Phillips, 2012b; Paap & Liu, 2014). For example, Kousaie and Phillips (2012b) found that differences in event-related potentials between bilinguals and monolinguals did not correspond to behavioral differences between groups in any task.

More recent studies have failed to observe evidence of a bilingual advantage in inhibitory control or other executive abilities (e.g., Duñabeitia et al., 2014; Gathercole et al., 2014; Goldman, Negen & Sarnecka, 2014; Hernández, Martin, Barceló, & Costa 2013; Kousaie & Phillips, 2012a; Kousaie & Phillips, 2012b; Namazi & Thordardottir, 2010; Paap & Greenberg, 2013; Paap & Liu, 2014). Duñabeitia et al. (2014) administered two Stroop tasks to 250 Spanish-Basque bilingual and 250 Spanish monolingual children. The authors did not observe a bilingual advantage in response times, accuracy rates, or interference effects and concluded that bilinguals do not seem to have an inhibitory control advantage. Similarly, Goldman et al. (2014) found that bilingual and monolingual children performed equivalently on a task that required them to attend to the number of stimuli while ignoring their size.

Gathercole et al. (2014) examined three tasks that previously demonstrated bilingual advantages: the Simon task, a card sorting task, and a metalinguistic task (e.g., Bialystok, 1988; Bialystok & Shapero, 2005; Martin-Rhee & Bialystok, 2008). In their study, over 350 individuals completed the metalinguistic task, over 550 participants completed the Simon task, and 650 participants completed the card sorting task. Gathercole et al. found no evidence of a bilingual advantage on any task. They argued that, if bilingual lexical representation is integrated, inhibiting cross-linguistic competitors should be similar to inhibiting contextually irrelevant meanings of a homograph. Further, language control is a function of linguistic contexts. The authors argued that this is similar to a monolingual's need to detect changes in tone, topic, turn-taking. Gathercole et al. posit that highly fluent bilinguals may have cognitive control mechanisms similar to those of monolinguals, so group differences should not be evident.

Paap and Greenberg (2013) investigated the bilingual advantage in inhibitory control, monitoring, and switching using several executive function tasks, including the Flanker task, the

Simon task, an antisaccade task, and a switching task. The authors found no evidence of a bilingual advantage on any measure, even for highly proficient balanced bilinguals. Paap and Greenberg used their findings to argue against a bilingual advantage in inhibitory control or executive processing. They further proposed that the executive processing advantage attributed to bilingualism could be explained by other factors, such as demographic factors, task-specific performance, or small sample size.

Paap and Liu (2014) investigated the bilingual inhibitory control advantage using a sentence processing task. Participants read sentences containing homographs followed by words related to the homograph, but that were contextually relevant or irrelevant. The authors hypothesized that if bilinguals have an inhibitory advantage, they should show less interference when processing the irrelevant meaning. However, there was no difference between bilinguals and monolinguals in interference suppression. The authors argued against a bilingual inhibitory control advantage in sentence processing and suggested that previous positive findings could be due to a combination of small sample size and confirmation bias. Consistently, bilingual executive processing advantages have not been observed in studies with large sample sizes (e.g., Duñabeitia et al., 2014; Gathercole et al., 2014). Using similar tasks, other researchers have also failed to observe inhibitory control advantages in bilingual adults (Kousaie & Phillips, 2012a, 2012b).

The purported bilingual advantage might be the result of a mediating factor, such as working memory (Namazi & Thordardottir, 2010). Working memory (WM) is a cognitive system that allows individuals to attend to goal-relevant memories (Shipstead, Lindsey, Marshall, & Engle, 2014). The mechanisms of WM include primary memory, attentional control, and secondary memory, each of which makes a contribution to WM (e.g., Shipstead et al., 2014; Unsworth & Engle, 2010). Further, WM is closely related to other executive functions. Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000) investigated the relationship between WM capacity and three executive functions: inhibition, task switching, and updating. All three executive functions were highly inter-related, with "inhibition" and "updating" demonstrating the strongest relationship. Further, WM capacity, as measured by the operation span task (Turner & Engle, 1989), was most strongly related to updating ability. Building on this model, Friedman, Miyake, Young, DeFries, Corley, and Hewitt (2008) showed that "inhibition" correlates almost perfectly with "general executive function" and strongly correlates with "updating." Similarly, other studies have reported a strong relationship between inhibition ability and WM span (e.g., Klauer, Schmitz, Teige-Mocigemba, & Voss, 2010; Unsworth & Spillers; 2010). Given this strong relationship, if bilinguals have an inhibitory control advantage, a similar advantage should be observed on WM tasks.

In most previous studies on bilingual executive function, WM span has been measured using simple span tasks, such as digit span, Corsi span, or matrix span (e.g., Bialystok, 2010; Luk, Anderson, Craik, Grady, & Bialystok, 2010; Martin-Rhee & Bialystok, 2008). The results have been inconsistent with some researchers reporting equivalent performance for monolinguals and bilinguals (e.g., Bialystok et al., 2004; Luo, Luk, & Bialystok, 2010; Martin-Rhee & Bialystok, 2008), others reporting a monolingual advantage (e.g., Bialystok, 2010), and still others reporting a bilingual advantage (e.g., Bialystok, et al., 2008; Morales, Calvo, & Bialystok, 2013).

In most studies, WM span is assessed using complex span tasks (e.g., Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004). The reading span task (Daneman & Carpenter, 1980) was developed to assess the processing and storage components of WM (Baddeley & Hitch, 1974). In this task, participants verify sentences while simultaneously remembering the last word of each sentence. Reading span was found to be highly predictive of aptitude measures, but simple span was not. Another commonly used complex span task is the operation span task, in which participants verify two step arithmetic problems while simultaneously remembering words (Turner & Engle, 1989). Similar to reading span, operation span was also a better predictor of aptitude than simple span. Turner and Engle proposed that the critical aspect of a complex span tasks is the inclusion of both processing and storage components (e.g., answering math problems while maintaining an updated list of words). Other complex span tasks include the rotation span task (Shah & Miyake, 1996), the counting span task (Case, Kurland, & Goldberg, 1982), and the symmetry span task (Unsworth, Heitz, Schrock, & Engle, 2005). These complex span tasks are reliable and significant predictors of performance on verbal reasoning tasks, standardized aptitude tests, intelligence measures, and attentional control measures (e.g., Daneman & Carpenter, 1980; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2004; Unsworth & Spillers, 2010). Further, Shipstead and colleagues (2014) argue that complex span reflects the primary memory, secondary memory, and attentional control aspects of WM.

Namazi and Thordardottir (2010) studied complex WM span and the “Simon effect” in bilingual and monolingual children. In the Simon task, participants quickly press buttons corresponding to the color of squares presented on a computer. The “Simon effect” is the additional time required when there is a mismatch between square location and button location. Previous researchers reported a bilingual advantage on the Simon task (e.g., Bialystok, et al., 2004; Martin-Rhee & Bialystok, 2008). Using a modified reading span task to measure WM span (Daneman & Carpenter, 1980; Gaulin & Campbell, 1994), Namazi and Thordardottir found that children with higher WM spans performed better on the Simon task than children with lower WM spans. However, there was no difference in performance between bilingual and monolingual children. The researchers concluded that WM was the critical factor associated with Simon task performance.

In previous bilingual studies, participants were administered only one complex span task that was verbal in nature (e.g., reading span, operation span). The present study investigated the bilingual advantage across different complex WM tasks. Further, participants were administered the standard operation span task (Turner & Engle, 1989) as well as a nonverbal complex span task. Past researchers have reported a bilingual disadvantage for verbal tasks (e.g., Bialystok & Craik, 2010; Bialystok, et al., 2008) and a bilingual advantage for nonverbal tasks (e.g., Emmorey, et al., 2008; Hilchey & Klein, 2011). Thus, to appropriately evaluate the relationship between WM and bilingualism, it is critical that WM span is assessed via verbal and nonverbal span tasks. In the current study, the symmetry span task (Unsworth et al., 2005) was used to measure nonverbal WM span. The symmetry span task requires simultaneous processing and storage of spatial information and has been previously used as a measure of nonverbal WM span (e.g., Kane et al., 2004; Unsworth & Spillers, 2010). The backward digit span task (a simple span task) was also included to allow for comparisons between the present study and previous studies. Given the previous reports of a bilingual inhibition control advantage and the strong relationship between the EF construct of inhibition and WM, a bilingual advantage was expected to emerge in the complex WM tasks. However, given prior reports of a bilingual verbal disadvantage, it was possible that a bilingual advantage would be observed only in the nonverbal symmetry span task.

Method

Participants

All participants were recruited from Arizona State University undergraduate classes and received partial course credit for their participation. Participants reported no history of memory, language, or neurological problems.

Fifty-three monolingual English speakers and 52 English-Spanish bilingual speakers participated in the experiment. A modified version of the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007) was used to measure relative language fluency in the bilingual participants (see Table 1). All participants gave informed consent and the experimental procedures were approved by the Arizona State University Human Subjects Institutional Review Board.

There were 28 females in the monolingual group and 22 females in the bilingual group. Monolinguals had a mean age of 19.4 years (SD = 5.15) and mean education of 13.6 years (SD = 0.28). Bilinguals had a mean age of 19.5 years (SD = 3.63) and a mean education of 13.8 years (SD = 0.67). The groups did not significantly differ in age, (t<1), but the bilingual group did have a significantly higher level of education than monolinguals ($t(100) = 2.38$, p=.019).[1]

(Table 1 about here)

Stimuli

A total of 150 words were selected for the operation span tasks. All English and Spanish word lists were balanced in word length and log frequency (i.e., the Spanish and English lists used in the operation span tasks were equivalent in length and frequency). The mean word length for all tasks was 4.6, with a range of 4.56 to 4.64 and the mean log frequency was 1.82 (range 1.81 to 1.82). Log frequencies were calculated based on Kučera and Francis norms (1967) and the LEXESP database (Sebastián-Gallés, Martí, Cuetos, & Carreiras, 2000). To calculate concreteness, Spanish words were translated into English and the English norms for concreteness were used (Gilhooly & Logie, 1980; Pavio, Yuille, & Madigan, 1968). The mean concreteness ratings were 474.21 and 470.15 for English and Spanish items, respectively. The symmetry span task stimuli were taken from Unsworth, Heitz, Schrock, and Engle (2005).

Procedure

The experiment was presented on standard PC-compatible computers using E-prime 1.2, an experimental operating system (Psychological Software Tools, 2002). Instructions and all experimental stimuli were presented in black, Arial 18 point font against a white background. The experimenter also read the instructions aloud. Individuals participated in groups of one to four people and were randomly assigned to one of four experimental orders. The experimental session consisted of four tasks: a backward digit span task, two operation span tasks (Turner & Engle, 1989), and a nonverbal symmetry span task (Kane et al., 2004). Tasks were presented in pseudo-random order for all participants with breaks between each task. Operation span tasks were not administered consecutively. The backward digit span task, operation span task, and symmetry span task contained four practice trials prior to experimental trials. Between each task, participants answered demographic questions.

Backward Digit Span Task. Participants were shown three to seven digits presented one at a time for 1000 ms each. At a prompt, participants typed the digits in reverse order. Participants were told to type an X if they forgot a number in the sequence. There were two trials at each span length and span lengths were presented in random order.

Operation Span Task. The operation span task is a standard complex WM task that is often used to assess WM span in monolinguals (Turner & Engle, 1989). On each trial, participants were shown a two-step math equation to verify (e.g., 3 + (4 x 2) = 11?) and a word to remember. They responded to the math equations by pressing keys marked YES and NO (the

P and Q keys on a standard keyboard, respectively) and received feedback after each response. Following feedback, a memory word was presented for 1000 ms. At a recall prompt, participants typed the words in presentation order. Participants were told to type an X if they forgot a word in the sequence. Sets contained three to seven equation-word pairs with two trials at each span length (e.g., a set of three trials required participants to remember three words). Span lengths were presented in random order. For bilingual participants, one operation span task included English words and one operation span task included Spanish words.[2]

Symmetry Span Task (Unsworth et al., 2005). Symmetry Span task performance has been previously used in several experiments as a measure of nonverbal WM span (Unsworth, Heitz, Schrock, & Engle, 2005). Participants were shown black and white images on a computer monitor and had 4000 ms to report whether the images were symmetrical around a vertical axis. To indicate that a picture was symmetrical, participants clicked on the image with a computer mouse, which triggered a YES and NO option to appear. After entering a response, participants were shown a 4 x 4 matrix with one square shaded red for 1000 ms. Following the matrix, another black and white image appeared for symmetry judgment. At a recall prompt, participants indicated the order of the presented red squares by clicking squares on a blank grid with the computer mouse. Participants were told to click a box marked BLANK if they forgot the location of a red square. They received feedback on their performance after each set. Sets contained two to six symmetry-memory matrices pairs with two trials at each span length (e.g., a set of six trials required participants to remember six red squares). Span lengths were presented in random order.

Task Scoring. All tasks were scored using a proportion correct scoring method (Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005; Unsworth & Engle, 2007). This scoring method reflects the number of items that the participant recalled in the correct serial order. For each item (e.g., digit, word, or red square) that was recalled in the correct serial order, a point was given. For the complex span tasks, a cutoff criterion of 80% accuracy on the YES/NO portion of the task was used to ensure that participants were attending to both parts of the WM tasks. Any participants scoring below 80% on the arithmetic problems or the symmetry verification were not included in the analysis (see Conway et al., 2005; Daneman & Carpenter, 1980; Engle et al., 1999 for similar cutoff criteria).

Operation span task responses were scored for five types of errors: omissions, transpositions, intrusions, phonemic errors, and partially recalled words. An *omission* error occurred when a word was not recalled. *Transpositions* occurred when a word was recalled, but in the wrong order. An *intrusion* occurred when a word from a previous set was recalled. In a *phonemic* error, a word was replaced with a phonologically similar word (e.g., "ground" for round). A *partial recall* occurred when part of the word was entered and it was unclear if the participant knew the target word (e.g., "ca" for camp). Misspelled words were considered correct if no other possible word could result from the given item (e.g., "wieght" was considered a correct response for "weight"). Misspelled words were presented to three independent raters and credit was given if all three raters agreed.

Results

Simple pairwise comparisons were initially conducted to compare monolingual and bilingual group performance within each task (see Table 2). The pairwise comparison revealed that the monolingual group had significantly higher operation span scores and backward digit span scores than the bilingual group, but groups did not significantly differ on the nonverbal symmetry span task.

(Table 2 about here)

To examine the relative predictive strength of WM span and bilingual status on task performance, a multivariate regression analysis was conducted that included operation span task performance, Speaker group status (Monolingual vs. Bilingual), and an Operation Span X Speaker Group interaction variable as predictor variables and backward digit span and symmetry span, as dependent variables (Note: The operation span term was centered prior to creating an interaction predictor, Aiken & West, 1991). For simple regression analyses, a Bonferroni adjusted alpha of .017 was used for multiple predictors. The results of the individual regression analyses (beta values, t-values, and p-values) are reported in Table 3.

(Table 3 about here)

In the overall multivariate analysis, operation span was a significant predictor of performance on all tasks ($F(90, 174.46) = 1.85$, $p<.001$). Neither Speaker Group ($F(3, 58) = .588$, $p=.625$) nor the interaction was a significant predictor of performance ($F(39, 172.50) = 1.35$, $p=.099$).

In the backward digit span task, the model with the two predictors and an interaction was statistically significant and accounted for 20% of the variance ($R^2_{Adjusted} = .198$, $F(3, 101) = 9.57$, $p<.001$). Operation span was a significant predictor of digit span: As operation span scores increased, digit span also increased. Although the simple pairwise comparison showed monolinguals recalled more digits than bilinguals, Speaker Group was not a significant predictor of digits when operation span was held constant. The interaction term also was not a significant predictor of digit span performance.

In the symmetry span task, the model containing two predictors and the interaction was statistically significant and accounted for 7% of the variance ($R^2_{Adjusted} = .071$, $F(3, 101) = 3.66$,

p=.015). Operation span significantly predicted performance: As operation span scores increased, performance on the nonverbal span task also increased. Neither Speaker Group status nor the Operation Span X Speaker Group interaction was a significant predictor of symmetry span task performance when operation span was held constant.

For the Spanish Operation Span Task, only data from the bilingual participants were included in the analyses. Operation Span was a significant predictor of performance and accounted for 35% of the variance ($R^2_{Adjusted}$ = .350, F(1, 50) = 57.05, p<.001). A simple planned comparison revealed no difference in performance on the English vs. Spanish versions of the operation span task (t(51) = 1.75, p=.087).

Error Analyses

Analyses were conducted on errors made in the operation span task. For omission errors, analyses were performed on the total number of errors. For all other error types, analyses were performed on the proportion of total responses. In the operation span task, simple pairwise comparisons revealed that the bilingual group made significantly more omission errors than the monolingual group. The two groups did not significantly differ in any other type of error. A multiple regression analysis was conducted on the number of omission errors with operation span, Speaker Group, and the Operation Span X Speaker Group interaction as predictors. A Bonferroni adjusted alpha of .017 was used for multiple predictors.

The model with two predictors and the interaction term was statistically significant and accounted for 7% of the variance ($R^2_{Adjusted}$ = .074, F(3, 101) = 3.75, p=.013). Speaker Group was a significant predictor of omissions (β= -.301, t(101) = 3.021, p= .003): Bilingual speakers made more omission errors than monolingual speakers. Operation span and the interaction were not significant predictors of omissions (β= .125, t<1, p= .343, and β= .128, $t(101)$ = 1.133, p= .260, respectively).

Discussion

This study examined performance of bilingual and monolingual speakers across verbal and nonverbal complex WM span tasks. Based on previous reports of a bilingual executive function advantage, bilinguals were expected to perform better than monolinguals on the WM tasks. However, no advantage was observed in either the verbal or nonverbal WM span tasks or in the backward digit span task. In the backward digit span task, bilinguals recalled fewer digits compared to monolinguals, but when operation span was held constant, Speaker Group was not a significant predictor of digit span. This finding is consistent with evidence showing that monolinguals and bilinguals generally perform equivalently on the backward digit span task and similar simple span tasks (e.g., Bialystok et al., 2004; Luo, et al., 2010; Martin-Rhee & Bialystok, 2008).

In the operation span task, the bilingual group had significantly lower span scores than the monolingual group. Although this finding seems to indicate a bilingual WM disadvantage, the monolingual and bilingual groups performed equivalently on the nonverbal, symmetry span task. Regression analyses were performed to see if bilingual status or WM span (standard operation span) was a stronger predictor of performance. WM span significantly predicted symmetry span task performance, but bilingual status did not.

The observation of lower operation span scores for the bilingual group relative to the monolingual group may be due to the verbal nature of the operation span task. Previous researchers have reported a bilingual disadvantage in verbal tasks (e.g., Bialystok, Craik, Green, & Gollan, 2009; Fernandes, Craik, Bialystok, & Kreuger, 2007). This disadvantage is proposed to stem from competing co-activated language representations and the processing cost associated with conflict resolution (e.g., Dijkstra & Van Heuven, 2002; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Green, 1998; Libben & Titone, 2009; Spivey & Marian, 1999). Alternatively, the verbal disadvantage may reflect differences in association strength. Relative to monolinguals, bilinguals use words in each language less frequently which may result in weaker connections between semantic and phonological/orthographic representations (e.g., Gollan, Montoya, Cera, & Sandoval, 2008; Gollan, Montoya, & Werner, 2002). The greater number of omission errors observed for the bilingual participants in the current study may also be reflective of weaker lexical associations. Other researchers have proposed that bilingual speakers can recruit additional executive functions to compensate for a verbal disadvantage. Luo, Luk, and Bialystok (2010) found that bilinguals retrieve fewer items than monolinguals in a semantic fluency task, but more items than monolinguals in a letter fluency task. This advantage was attributed to the higher demand for executive control in the letter fluency task relative to the semantic fluency task. Similarly, Bialystok and Feng (2009) showed that, despite lower vocabulary scores, bilinguals performed similarly to monolinguals in a proactive interference task. Moreover, bilinguals made fewer errors than monolinguals indicating better executive control.

The fact that no bilingual advantage was observed in the symmetry span task suggests that previously observed bilingual executive function advantages may be driven by a specific, rather than a general, aspect of executive function. For example, a bilingual advantage may only arise when the task requires some degree of conflict resolution or switching between tasks (e.g., Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Hilchey & Klein, 2011; Prior & Macwhinney, 2009). Bilingual advantages in conflict resolution and task switching would be consistent with both the Inhibitory Control Model and the Adaptive Control Hypothesis, which assume that bilinguals use these processes for language control (Green, 1998; Green & Abutalebi, 2013). However, it should be noted that bilingual executive advantages are not consistently observed in tasks requiring conflict resolution or inhibitory control (e.g., Kousaie & Phillips, 2012; Paap & Greenberg, 2013; Paap & Liu, 2014). Given that the bilinguals in the present study performed equivalently or worse than monolinguals on the WM tasks, our results do not support a bilingual advantage in WM. Further, these results suggest that bilinguals may not have a specific advantage in inhibitory control, due to the strong relationship between WM and inhibition.

It may be argued that our failure to observe a bilingual advantage was related to the participant sample, which consisted of young adults. While some researchers have reported bilingual advantages in young adults (e.g., Costa, Hernández, & Sebastián-Gallés, 2008), other researchers have observed diminished effects of bilingualism in young adults relative to effects observed in children and older adults (Bialystok et al., 2004; Bialystok et al., 2008). Thus, one may argue that a bilingual advantage was present, but it was too small to be detected in our young adult sample. However, this explanation seems unlikely given that no trends toward a bilingual advantage were observed in any of the tasks.

The present results are consistent with Namazi and Thordardottir (2010), who reported that WM span (operation span) significantly predicted performance on other WM tasks, and when WM span was held constant, bilingual status did not significantly predict performance. Our results also indicate that previously observed bilingual executive function advantages cannot be solely attributed to increased WM capacity. The performance differences between bilingual and monolingual speakers on executive function tasks may instead reflect relative strengths in specific executive function processes which are only revealed under certain task conditions, such as conflict resolution or task switching.

It is possible that lifelong bilingualism results in improved switching ability, but not improved inhibitory control. The executive function of switching is less strongly related to updating and inhibition (e.g., Klauer et al., 2010; Miyake et al., 2000) suggesting that WM span may not predict switch costs between bilinguals and monolinguals. Indeed, some studies have reported a bilingual advantage in switching (e.g., Prior & Gollan, 2011; Prior & Macwhinney, 2009), although even this effect has not been consistent (e.g., Hernández et al., 2013; Paap & Greenberg, 2013).

The previously observed bilingual advantage in executive function was not apparent in our set of complex WM tasks. Miyake et al. (2000) established an executive function framework in which updating, inhibition, and switching were diverse, but highly related abilities. Updating and inhibition shared the strongest relationship, and operation span task performance was most representative of updating. If there is a bilingual inhibitory control advantage, group differences should be observed in complex WM tasks. However, in this study, neither the verbal nor the nonverbal WM tasks revealed a bilingual advantage. Additionally, individual WM span was a stronger predictor of nonverbal complex span and simple span performance than bilingual status. Future studies should examine the role that task demands play in the engagement of specific executive function mechanisms and how bilingual status relates to those processes.

References

Aiken, L. S., & West, S. G. (1991). *Multiple regression: Testing and interpreting interactions*. Newbury Park, CA: Sage.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology*, *106*(1), 20-29.

Alloway, T. P., Gathercole, S. E., Willis, C., & Adams, A.M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology*, *87*(2), 85–106.

Ardila, A., Rosselli, M., Ostrosky-Solís, F., Marcos, J., Granda, G., & Soto, M. (2000). Syntactic comprehension, verbal memory, and calculation abilities in Spanish-English bilinguals. *Applied Neuropsychology*, *7*(1), 3–16.

Bialystok, E. (2010). Global-local and trail-making tasks by monolingual and bilingual children: Beyond inhibition. *Developmental Psychology*, *46*(1), 93–105.

Bialystok, E. & Craik, F. I. M. (2010). Bilingualism and aging. *Memory, Aging and the Brain*, *1*, 115–131.

Bialystok, E., Craik, F. I. M., Grady, C., Chau, W., Ishii, R., Gunji, A., & Pantev, C. (2005). Effect of bilingualism on cognitive control in the Simon task: Evidence from MEG. *NeuroImage*, *24*(1), 40–49.

Bialystok, E., Craik, F. I. M., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, *10*(3), 89–129.

Bialystok, E., Craik, F. I. M., Klein, R., & Viswanathan, M. (2004). Bilingualism, aging, and cognitive control: Evidence from the Simon task. *Psychology and Aging*, *19*(2), 290–303.

Bialystok, E., Craik, F. I. M., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(4), 859–873.

Bialystok, E., Craik, F. I. M., & Luk, G. (2012). Bilingualism: Consequences for mind and brain. *Trends in Cognitive Sciences*, *16*(4), 240–250.

Bialystok, E. Craik, F. I. M., & Ruocco, A. C. (2006). Dual-modality monitoring in a classification task: The effects of bilingualism and aging. *The Quarterly Journal of Experimental Psychology*, *59*(11), 1968–1983.

Bialystok, E., Craik, F. I. M., & Ryan, J. (2006). Executive control in a modified antisaccade task: Effects of aging and bilingualism. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(6), 1341–1354.

Bialystok, E., & Feng, X. (2009). Language proficiency and executive control in proactive interference: Evidence from monolingual and bilingual children and adults. *Brain and Language*, *109*(2-3), 93–100.

Bialystok, E., & Martin, M. M. (2004). Attention and inhibition in bilingual children: Evidence from the dimensional change card sort task. *Developmental Science, 7*(3), 325–339.

Bialystok, E., & Viswanathan, M. (2009). Components of executive control with advantages for bilingual children in two cultures. *Cognition*, *112*(3), 494–500.

Campbell, T., Dollaghan, C., Needleman, H., & Janosky, J. (1997). Reducing bias in language assessment: Processing-dependent measures. *Journal of Speech, Language, and Hearing Research, 40*, 519–525.

Case, R., Kurland, M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, *33*, 386–404.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*, 163–183.

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769–786.

Costa, A., Hernández, M., Costa-Faidella, J., & Sebastián-Gallés, N. (2009). On the bilingual advantage in conflict processing: Now you see it, now you don't. *Cognition*, *113*(2), 135–149.

Craik, F. I. M., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory & Cognition, 34*(6), 1236–1249.

Daneman, P., & Carpenter, M. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450–466.

De Groot A. M. B., Delmaar, P., & Lupker, S. J. (2000). The processing of interlexical homographs in translation recognition and lexical decision: Support for non-selective access to bilingual memory. *The Quarterly Journal of Experimental Psychology*, *53A*, 397-428.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378*, 279-281.

Dijkstra, T. & van Heuven, W. J. B. (1998). The BIA model and bilingual word recognition. In: J. Grainger, & A. M. Jacobs (Eds.), *Localist Connectionist Approaches to Human Cognition* (pp. 189-225). Maywah, N. J.: Lawrence Erlbaum Associates.

Dijkstra, T., & Van Heuven, W. J. B. (2002). The architecture of the bilingual word recognition system: From identification to decision. *Bilingualism: Language and Cognition*, *5*(3), 175-197.

Dijkstra T., Van Jaarsveld H., & Ten Brinke S. (1998). Interlingual homograph recognition: effects of task demands and language intermixing. *Bilingualism: Language & Cognition*, *1*, 51-66.

Duñabeitia, J. A., Hernández, J. A., Antón, E., Macizo, P., Estévez, A., Fuentes, L. J., & Carreiras, M. (2014). The inhibitory advantage in bilingual children revisited. *Experimental Psychology*, *61*(3), 234–51.

Emmorey, K., Luk, G., Pyers, J. E., & Bialystok, E. (2008). The source of enhanced cognitive control in bilinguals: Evidence from bimodal bilinguals. *Psychological Science*, *19*(12), 1201–1206.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General*, *128*(3), 309–331.

Fernandes, M. A., Craik, F., Bialystok, E., & Kreuger, S. (2007). Effects of bilingualism, aging, and semantic relatedness on memory under divided attention. *Canadian Journal of Experimental Psychology*, *61*(2), 128–141.

Friedman, N. P., Miyake, A., Young, S. E., Defries, J. C., Corley, R. P., & Hewitt, J. K. (2008). Individual differences in executive functions are almost entirely genetic in origin. *Journal of Experimental Psychology: General*, 137(2), 201–225.

Gathercole, V. C. M., Thomas, E. M., Kennedy, I., Prys, C., Young, N., Viñas Guasch, N. Roberts, E. J., Hughes, E. K., & Jones, L. (2014). Does language dominance affect cognitive performance in bilinguals? Lifespan evidence from preschoolers through older adults on card sorting, Simon, and metalinguistic tasks. *Frontiers in Psychology*, *5*(February), 11.

Gaulin, C., & Campbell, T. F. (1994). A procedure for assessing verbal working memory in normal school-age children: Some preliminary data. *Perceptual and Motor Skills*, *79*, 55–64.

Gilhooly, K. J., & Logie, R.H. (1980). Age of acquisition, imagery, concreteness, familiarity and ambiguity measures for 1944 words. *Behaviour Research Methods and Instrumentation 12*, 395-427.

Goldman, M. C., Negen, J., & Sarnecka, B. W. (2014). Are bilingual children better at ignoring perceptually misleading information? A novel test. *Developmental Science*, 1–9.

Gollan, T. H., Montoya, R. I., Cera, C., & Sandoval, T. C. (2008). More use almost always a means a smaller frequency effect: Aging, bilingualism, and the weaker links hypothesis. *Journal of Memory and Language*, *58*(3), 787–814.

Gollan, T. H., Montoya, R. I., & Werner, G. A. (2002). Semantic and letter fluency in Spanish-English bilinguals. *Neuropsychology*, *16*(4), 562–576.

Green, D. (1998). Mental control of the bilingual lexico-semantic system. *Bilingualism: Language and Cognition*, *1*, 67–81.

Green, D. W., & Abutalebi, J. (2013). Language control in bilinguals: The adaptive control hypothesis. *Journal of Cognitive Psychology*, *25*(5), 515–530.

Hernández, M., Martin, C. D., Barceló, F., & Costa, A. (2013). Where is the bilingual advantage in task-switching? *Journal of Memory and Language*, *69*(3), 257–276.

Hilchey, M. D., & Klein, R. M. (2011). Are there bilingual advantages on nonlinguistic interference tasks? Implications for the plasticity of executive control processes. *Psychonomic Bulletin & Review*, *18*(4), 625–658.

Holtzheimer, P., Fawaz, W., Wilson, C., & Avery, D. (2005). Repetitive transcranial magnetic stimulation may induce language switching in bilingual patients. *Brain and Language, 94*, 274 –277.

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2007). Variation in working memory capacity as variation in executive attention and control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variations in working memory* (pp. 21– 48). New York, NY: Oxford University Press.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review*, *9*(4), 637–671.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, *133*(2), 189–217.

Klauer, K. C., Schmitz, F., Teige-Mocigemba, S., & Voss, A. (2010). Understanding the role of executive control in the implicit association test: why flexible people have small IAT effects. *Quarterly Journal of Experimental Psychology*, *63*(3), 595–619.

Kousaie, S., & Phillips, N. A. (2012a). Ageing and bilingualism: Absence of a “bilingual advantage” in Stroop interference in a nonimmigrant sample. *Quarterly Journal of Experimental Psychology*, *65*(2), 356–369.

Kousaie, S., & Phillips, N. A. (2012b). Conflict monitoring and resolution: Are two languages better than one? Evidence from reaction time and event-related brain potentials. *Brain Research, 1446*, 71–90.

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Libben, M. R., & Titone, D. A. (2009). Bilingual lexical access in context: Evidence from eye movements during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(2), 381–390.

Luk, G., Anderson, J. A. E., Craik, F. I. M., Grady, C., & Bialystok, E. (2010). Distinct neural correlates for two types of inhibition in bilinguals: Response inhibition versus interference suppression. *Brain and Cognition*, *74*(3), 347–357.

Luo, L., Luk, G., & Bialystok, E. (2010). Effect of language proficiency and executive control on verbal fluency performance in bilinguals. *Cognition*, *114*(1), 29–41.

Marian, V., Blumenfeld, H. K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency Questionnaire (LEAP-Q): Assessing language profiles in bilinguals and multilinguals. *Journal of Speech, Language, and Hearing Research*, *50*, 940–968.

Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, *11*(1), 81–93.

Mechelli, A., Crinion, J. T., Noppeney, U., O'Doherty, J., Ashburner, J., Frackowiak, R. S., Price, C. J. (2004). Structural plasticity in the bilingual brain: Proficiency in a second language and age at acquisition affect grey-matter density. *Nature, 431*(7010), 757.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex “Frontal Lobe” tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100.

Morales, J., Calvo, A., & Bialystok, E. (2013). Working memory development in monolingual and bilingual children. *Journal of Experimental Child Psychology*, *114*(2), 187–202.

Namazi, M., & Thordardottir, E. (2010). A working memory, not bilingual advantage, in controlled attention. *International Journal of Bilingual Education and Bilingualism*, *13*(5), 597–616.

Paap, K. R., & Greenberg, Z. I. (2013). There is no coherent evidence for a bilingual advantage in executive processing. *Cognitive Psychology*, *66*(2), 232–258.

Paap, K. R., & Liu, Y. (2014). Conflict resolution in sentence processing is the same for bilinguals and monolinguals: The role of confirmation bias in testing for bilingual advantages. *Journal of Neurolinguistics*, *27*(1), 50–74.

Pavio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery and meaningfulness values for 925 words. *Journal of Experimental Psychology Monograph Supplement*, 76 (3, part 2).

Prior, A., & Gollan, T. H. (2011). Good language-switchers are good task-switchers: Evidence from Spanish–English and Mandarin–English bilinguals. *Journal of the International Neuropsychological Society*, *17*(04), 682–691.

Prior, A., & Macwhinney, B. (2009). A bilingual advantage in task switching. *Bilingualism: Language and Cognition*, *13*(2), 253-262.

Rodriguez-Fornells, A., Van der Lugt, A., Rotte, M., Britti, B., Heinze, H.-J., & Münte, T. F. (2005). Second language interferes with word production in fluent bilinguals: Brain potential and functional imaging evidence. *Journal of Cognitive Neuroscience, 17*(3), 422–433.

Sebastián-Gallés, N., Martí, M. A., Cuetos, F., & Carreiras, M. F. (2000). *LEXESP: Léxico informatizado del español [LEXESP: A computerized word-pool in Spanish]*. Barcelona: Edicions de la Universitat de Barcelona.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime Version 1.0 [Computer software]*. Pittsburgh: Psychology Software Tools Inc.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology. General*, *125*(1), 4–27.

Shipstead, Z., Lindsey, D. R. B., Marshall, R. L., & Engle, R. W. (2014). The mechanisms of working memory capacity: Primary memory, secondary memory, and attention control. *Journal of Memory and Language, 72*, 116–141.

Spivey, M., J., & Marian, V. (1999). Cross talk between native and second languages: Partial activation of an irrelevant lexicon. *Psychological Science, 10*(3), 281–284.

Turner, M., Engle, R. W. (1989). Is Working Memory Capacity Task Dependent? *Journal of Memory and Language*, *28*(2), 127–154.

Unsworth, N., & Engle, R. W. (2006). A temporal-contextual retrieval account of complex span: An analysis of errors. *Journal of Memory and Language, 54*, 346-362.

Unsworth, N., & Engle, R. W. (2007). On the division of short-term and working memory: an examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin, 133*(6), 1038–1066.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*(3), 498–505.

Unsworth, N., & Spillers, G. J. (2010). Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model. *Journal of Memory and Language*, *62*(4), 392–406.

Footnotes

[1] Parental education was not included as an indicator of socioeconomic status. Studies have shown that complex span tasks are less susceptible to the effects of socioeconomic and cultural influences (e.g., Alloway & Alloway, 2010; Campbell, Dollaghan, Needleman, Janosky, 1997) and that education level of the participant demonstrates the same relationship to complex span task performance as maternal education (e.g., Alloway, Gathercole, Willis, & Adams, 2004). Additionally, the bilingual participants in this study had significantly more years of education than the monolingual participants suggesting that there was no disadvantage.

[2] To control for possible fatigue effects across the two speaker groups, monolingual participants performed the operation span task in English twice. The correlation between the two tasks for monolinguals was $r(52) = .714$, $p<.001$, which is consistent with previous studies (Conway et al., 2005; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002).

Table 1

Language Profile for Bilingual Participants.

Self-ratings for Spanish		Self-ratings for English		Comparisons
Daily Use	25.06% (16.98)	Daily Use	74.94% (16.98)	49.43*
Age of Acquisition	1.42 (3.34)	Age of Acquisition	4.00 (3.89)	2.58*
Age Fluent	6.60 (4.78)	Age Fluent	6.97 (3.61)	0.37
Age Began Reading	8.31 (4.18)	Age Began Reading	6.49 (2.53)	1.82
Age Fluent Reading	10.42 (4.59)	Age Fluent Reading	8.59 (3.00)	1.83
Proficiency[a]		Proficiency[a]		
Speaking	7.85 (1.50)	Speaking	9.58 (0.64)	1.73*
Understanding	9.00 (1.19)	Understanding	9.77 (0.51)	0.77*
Reading	7.83 (1.56)	Reading	9.67 (0.51)	1.84*

[a] Self-ratings for proficiency questions are based on a 10-point scale.

Note: Standard deviations are in parentheses. Cross language comparisons were evaluated using a Bonferroni corrected alpha of .006 for eight simultaneous comparisons.

*p<.006.

Table 2

Mean Score on Tasks by Speaker Group and Speaker Group Differences.

Task	Monolingual	Bilingual	Speaker Group Difference
Backward Digit	39.47 (6.75)	35.62 (7.37)	-3.86 [2.80, *p*=.006]
Operation Span	34.68 (6.73)	29.87 (7.96)	-4.81 [3.35, *p*=.001]
Spanish Operation Span		27.78 (7.99)	
Symmetry Span	23.23 (6.44)	22.44 (7.07)	-0.78 [0.60, *p*=.553]

Note. Standard deviations are in parentheses. *t*-values and *p*-values are in brackets. Positive values indicate a bilingual advantage.

Table 3

Regression Analyses including Operation Span and Bilingualism as Predictors for Task Performance

Task	*Beta*	*t*	*p*
Backward Digit Span			
Operation Span	0.521	3.658	<0.001*
Speaker Group	0.137	1.481	0.142
Interaction	0.139	1.168	0.246
Symmetry Span			
Operation Span	0.309	2.357	0.020*
Speaker Group	-0.044	0.483	0.662
Interaction	0.022	0.174	0.862
Spanish Operation Span			
Operation Span	0.597	7.553	<0.001*