Effect of Bilingualism on Working Memory

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Abstract

Although research suggests that bilingualism leads to heightened executive functions, no consensus has been reached on how it might affect working memory, a cognitive ability closely related to executive functions. Results from previous studies suggest that bilingualism might act on specific aspects of working memory differently. By testing Spanish-English bilinguals and English monolinguals in two wordlist recall experiments, I investigated two possible effects bilingualism might have on working memory. Experiment 1 explored whether bilinguals' enhanced executive functions will boost working memory performance in tasks with high inhibitory control demands by comparing subjects' performance in a directed forgetting paradigm. Experiment 2 examined how bilinguals' parallel language activation affects working memory by measuring the phonological similarity effect of the nonresponse language. Results from Experiment 1 indicate that bilinguals are significantly better at inhibiting distractions in working memory tasks. No evidence was found in Experiment 2 that would indicate any interference from parallel language activation in verbal working memory.

Introduction

Bilingualism is common: According to an estimation by Kroll and DeGroot (2005), more than half of the world's population today uses more than one language in their everyday life. A number of studies have examined the cognitive effects of bilingualism, many of which have claimed cognitive benefits for being bilingual, such as improving people's inhibitive control ability and protecting against age-related cognitive decline (Bialystok, 2001). Among other things, bilinguals have often been found to outperform monolinguals in experimental tasks that require inhibition of task-irrelevant information, such as the Simon task, Flanker task (Costa et al., 2009), and Stroop task (Bialystok, 2009), leading many scholars to conclude that bilingualism improves executive functions (Blumenfeld & Marian, 2011; Bialystok, 2010; Bialystok et al., 2004). Although some scholars have argued that these findings are only shown in studies with small sample sizes and questionable data analysis methods (Paap et al., 2015), the idea that bilingualism enhances executive functions still remains a prominent argument in the field of cognitive psychology.

Executive functions are generally defined as cognitive abilities that guide goal-directed behavior in non-routine situations (Banich, 2009), and are said to include three components: shifting, updating, and inhibition (Miyake et al., 2000). The inhibition component, in particular, is believed to be enhanced by bilinguals' constant suppression of one of their languages in order to resolve the competition between their two language systems in everyday speech production (Bialystok, 2010, Bialystok et al., 2004; Hilchey and Klein, 2011).

Working memory has been considered to be either part of, or closely related to, executive functions (Bialystok, 2009). The concept of working memory, which was first proposed by Baddeley and Hitch (1974), refers to a system that temporarily holds information in an accessible state for carrying out complex cognitive tasks. An example of a task requiring working memory is keeping in mind an unfamiliar phone number you have just heard in order to enter it into your phone. Working memory capacity can be measured in simple span tasks such as word or digit span tests, and complex span tasks such as operation span and reading span tests (Engle & Kane, 2003). No matter their exact definitions, it can be safely said that these two cognitive mechanisms are closely related, an argument proved by studies finding high correlations between people's performances in these two types of cognitive tasks (Engle, 2002; Engle & Kane, 2003). These correlations strongly imply a shared executive attention mechanism between executive functions and working memory (McCabe et al., 2010).

Given the close relationship between executive functions and working memory, the fact that bilinguals show enhanced executive functions leads to a natural assumption that a bilingual advantage would also be seen for working memory as well. However, despite many studies of the link between bilingualism and working memory, the results are inconclusive. Some studies have found no difference between the performance of bilinguals and monolinguals in various working memory tasks (Engel de Abreu, 2011; Bialystok et al., 2008; Namazi & Thordardottir, 2010), while others have found a bilingual advantage in certain

types of working memory tasks or under certain conditions (Teubner-Rhodes et al. 2016; Hernández, Costa, & Humphreys, 2012; Morales, Calvo, & Bialystok, 2013).

Some scholars have proposed that this apparent inconsistency in study results could be explained by bilingualism affecting specific aspects of working memory differently (Calvo, Ibáñez, & García, 2016; Bialystok, 2009). A closer look at existing literature also seems to support this argument. On the one hand, working memory tasks that bilinguals were found to perform better in often have high executive control demands. In other words, the inhibition of some distracting information is needed to complete the task. In one study done by Teubner-Rhodes et al. (2016), both bilingual and monolingual subjects were tested in N-back tasks, in which they see a continuous stream of words and have to indicate when they see a word that was repeated N words back. Bilinguals outperformed monolinguals in a high-conflict version of the task, where lures (words that were repeated, but not in the right positions) were added, but not in no-conflict ones. Another study done by Hernández, Costa, & Humphreys (2012) found that bilinguals were less affected by irrelevant information in a visual search test, but were as affected by priming and unique items as monolinguals. These results seem to indicate that bilingualism does have some positive influence on working memory, but that the influence only emerges in tasks that have a high cognitive control demand. Given the argument that bilingualism enhances executive functions, this result does indeed make sense.

On the other hand, working memory tasks using words or digits as stimuli often showed no difference between the performance of monolinguals and bilinguals. Tasks employing

non-verbal visual stimuli, however, such as spatial working memory tasks (recalling order of items) or corsi block tasks (recalling the order in which the experimenter tapped a collection of spatially separated blocks), would sometimes show a bilingual advantage (Feng, 2009; Bialystok, 2008; Namazi and Thordardottir, 2010). Research has shown that compared to monolinguals, bilinguals have weaker verbal and vocabulary skills, and slower word comprehension and production (Bialystok et al., 2010; Bialystok et al., 2008; Costa & Santesteban, 2004; Gollan et al., 2007). Therefore, when verbal working memory tasks fail to show better performance for bilinguals over monolinguals, many scholars have used bilinguals' weaker verbal and vocabulary skills as an explanation for that result (Bialystok, 2010; Engel de Abreu, 2011; Calvo, Ibáñez, & García, 2016). However, this argument does not appear to be a perfect explanation. In the study done by Engel de Abreu (2011), bilingual and monolingual subjects were also tested on their language abilities (vocabulary and syntax) in addition to working memory tasks. The results showed no difference between the two groups of subjects in the working memory task, and the lack of difference could not be explained by their performance in the language task.

Bilinguals' parallel language activation is another factor besides weaker vocabulary skills that could explain bilinguals' lackluster performance in verbal working memory tasks. Studies have shown that when bilinguals are only consciously using one language, their second language also remains activated, despite an effort at inhibition. In semantic judgment tasks, a distinct difference in the graphical forms between the two words in the to-be-judged word pairs in bilinguals' non-response language could result in slower response times

(Morford et al., 2011) or a larger N400 brain potential (Thierry & Wu, 2007) compared to when the forms of the two words are more similar to each other in the non-response language. In speech production tasks, similarity in the pronunciation of words across the two languages (cognates) produces faster responses for bilinguals in lexical decision tasks (deciding whether stimuli are words or nonwords) but slower responses in word naming tasks (naming words as fast as possible) (Van Hell & Dijkstra, 2002; Jared & Kroll, 2001). Lexical bias effect, which is the tendency to produce more phonological substitution errors in speech production when the resulting errors are real words rather than nonwords, was also found to exist across languages, meaning that when reading aloud word pairs, bilinguals make more phonological substitution mistakes (switching around syllables in the two words) when the resulting error produces real words in the nonresponse language (Costa, Roelstraete, & Hartsuiker, 2006). These studies show that despite an effort at inhibition, the graphical, phonological, and semantic information of bilinguals' nonresponse language still remains activated, and could interfere with task performance in the tested language. Although the effect of parallel language activation has only been studied in language processing tasks, it is likely that this effect arises in verbal working memory tasks as well. Based on these previous studies, it is likely that working memory is affected by bilingualism differently through subjects' heightened executive functions and their parallel activation of two language systems. While the former should have a beneficial effect in working memory tasks that require high levels of executive control, the latter is likely to produce a negative effect on performance in certain verbal working memory tasks.

To test this hypothesis, in the present study two word recall tasks were given to Spanish-English bilinguals and English monolinguals. Experiment 1 aimed to determine whether bilinguals are better at conflict resolution in working memory tasks. This task used a directed forgetting paradigm, which means subjects were presented with words that they were either instructed to remember or to forget. In this paradigm, subjects have to actively inhibit the distraction of the to-be-forgotten items when asked to recall words. By comparing the performance of bilingual and monolingual subjects, this experiment could reveal whether bilinguals are better at employing inhibitory control and resolving the conflict between target words and distractors in working memory. Although there have been studies on bilinguals' performance in working memory tasks with high conflicts, it is important to note that directed forgetting has never been utilized before. Thus, results from Experiment 1 could be an important addition to existing literature. Experiment 2 aimed to determine the effects of parallel language activation on bilinguals' performance in working memory tasks. Experiment 2, which was also a wordlist recall task, asked whether the phonological similarity effect, the phenomenon that similar-sounding words are harder to remember (Conrad & Hull, 1964), could be seen across bilinguals' two languages. By looking at bilingual subjects' performance in trials where target words sounded dissimilar in the tested language yet their translations sounded similar in subjects' unsolicited second language, this experiment could reveal whether the parallel activation of both languages has an effect on bilinguals' working memory performance.

Experiment 1

Rationale:

Considerable research evidence shows that bilingualism strengthens executive functions (Blumenfeld & Marian, 2011). Bilinguals have also been shown to outperform monolinguals in many working memory tasks with high demands of executive control (Teubner-Rhodes et al., 2016; Hernández, Costa, & Humphreys, 2012). Based on the close associations between executive functions and working memory, and bilinguals' enhanced performance in select working memory tasks (Engle & Kane, 2003), I hypothesized that bilingualism boosts performance in high demand working memory tasks by strengthening executive functions. I tested this specific aim in Experiment 1 by introducing conflict into a wordlist recall task.

One striking example of conflict in a working memory task is the proactive interference effect (interference from previously encoded material) in a directed forgetting paradigm, as shown in a study done by Tehan and Humphreys (1995). In a directed forgetting paradigm, subjects study different lists and are later instructed to forget some of those lists and remember others, which means the to-be-forgotten items have to be inhibited in some way. Tehan and Humphreys found that when a phonologically similar foil was present in the to-be-forgotten list, subjects showed significantly worse recall of the target word in the to-be-remembered list in the same trial. The same interference effect was also found for semantically related foils in a cued recall task when recall is done after a filled delay period where immediate phonological recall is interrupted. In this study, Experiment 1 replicates the design of Experiment 3 from the Tehan and Humphreys study (1995) in order to see whether

bilinguals show less proactive interference effect with semantically-related foils. This experiment is the first to have tested bilingual subjects in a category cued recall task using directed forgetting.

Subjects:

Twenty Spanish-English bilingual and 20 English monolingual Rice undergraduate students participated in this study. All subjects received credit toward course requirements or monetary compensations for their participation. For the purpose of data collection, in this study, English monolinguals were defined as native English speakers whose self-rated proficiency levels in a second language, if at all, were no higher than 5 out of 10. Spanish-English bilinguals were defined as people who had acquired both languages before the age of 6, and who rated their proficiency levels in both languages at or above 7 out of 10 at the time of testing. To confirm that bilingual subjects were not falsely reporting their Spanish proficiency, these subjects also had to pass a Spanish picture-naming task with a correct rate higher than 75%.

The ages of language acquisition and self-rated proficiency levels for all subjects were collected through the Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld, & Kaushanskaya, 2007), which subjects completed at the start of the testing session. Proficiency level was calculated by averaging the three proficiency ratings on speaking, understanding spoken language, and reading. In the Spanish picture-naming task that bilingual subjects also completed, 62 black and white line drawings of common objects from Snodgrass and Vanderwart (1980) were shown on the screen at a rate of 3 seconds per

picture, during which time subjects had to name the depicted objects in Spanish. Subjects' SAT scores were also collected at the end of each testing session to control for possible effects of general cognitive abilities. In total, 35 subjects provided their highest SAT or ACT scores. One bilingual and four monolinguals refused to disclose this information. In the analysis, ACT scores were converted to equivalent SAT scores using College Board's official concordance tools.

Among the 20 monolinguals that participated in this study, 5 were male and 15 were female. Their average age was 19.55 (SD=1.15). All monolingual subjects were native English speakers. Their average age of acquisition (AOA) for a second language, if any, was between 11 and 12 years old. Only one monolingual subject had no prior exposure to any second language at all. Their average proficiency rating for English was 9.75/10 (SD=0.55), and for a second language it was 2.44/10 (SD=1.77).

Among the 20 bilinguals, 11 were male and 9 were female. Their average age was 19.85 (SD=2.25). All bilingual subjects were native Spanish speakers. Their AOA for English was very early, with the average age around 4 years old. Their average proficiency rating for English was 9.48 (SD=0.55), and for Spanish it was 8.63 (SD=1.00). Their average correct rate in the Spanish picture-naming task was 91.2% (SD=0.06). From these statistics we can see that while Spanish was the first language for all subjects, English was their dominant language at the time of testing. Overall, this was a group of bilinguals with very high proficiency levels and very early AOAs in both languages. They are therefore prime subjects for a study looking for the effects of bilingualism.

The average SAT score for monolinguals was 2224.38 (SD=136.97). The average SAT score for bilinguals was 2076.84 (SD=169.48). The score for bilinguals is significantly lower than monolinguals, with $t(33)= 2.84$, $p = 0.004$. This difference in SAT scores between bilingual and monolingual college students is a standard finding in the literature, and is generally explained by bilinguals' lower language abilities in English (Pearson, 1993).

Materials:

Experiment 1 contained 20 one-list trials and 20 two-list trials. Each list in the one-list condition contained four semantically unrelated filler words. Half of the two-list trials were in the critical condition and half in the control condition. Trials in the critical condition contained three semantically unrelated filler words and one semantic foil in the first list, and three semantically unrelated filler words and one target word in the second list. The foil and target belonged in the same taxonomic category. Trials in the control condition contained four semantically unrelated words in the first list, and three semantically unrelated filler words and one target word in the second list. Replicating the design of Experiment 3 in the Tehan and Humphreys study (1995), to construct the wordlists, 30 taxonomic categories with 8 words belonging in each category were chosen from the McEvoy and Nelson (1994) study. Separate word pools were constructed for the one-list filler trials and the two-list trials so that there was no overlap between the tested categories of one-list and two-list trials. To eliminate any primacy (tendency of having better recall for the first item in a list) or recency effects (tendency of having better recall for the last item in a list), Experiment 1 followed the design of the Tehan and Humphreys study in only presenting semantic foils and target words in the

second or third sequential positions in each wordlist.

Procedure:

At the beginning of the experiment, subjects were told that they would be shown a series of one-list and two-list trials, but that they would only be tested on the last four items they were shown, which would be all four words in the one-list trials and the second list of the two-list trials. During the test, one-list and two-list trials were randomly presented, so subjects never knew whether the words they were currently seeing would be tested or not, and would therefore pay attention to every item.

All the stimuli were presented in the same testing session on a computer using PsyScope software (version X B77). Two scripts with different trial sequences were created, with trials from the control, critical, and filler conditions randomly mixed. Category cues and target words for the critical and control conditions were also chosen differently for the two scripts to further eliminate any potential interference from word length or frequency. After instructions were given and before the task began, subjects were shown all the test material organized by category, so that there would be no confusion on which words belonged in which category. After subjects were familiarized with the test material, they were then given a practice trial that had two lists with a foil in the first list. Material in the practice trial was separate from material for the actual task.

At the beginning of each experimental trial, an asterisk ("*") was shown for 2 seconds, after which each word in the given list was presented individually for one second on the screen. In two-list trials, an exclamation mark ("!") was presented for 1 second after the last

word in the first list was presented, signifying that subjects should forget the four words they had just seen and focus on remembering the next list. After each trial, there was a 2-second filled retention interval in which subjects read aloud two strings of random four-digit numbers presented on the screen at 1second per string, before being given a category cue in all caps for recall. The category cue was presented on the screen for 2 seconds, after which subjects had an additional 5 seconds to respond with a word belonging to the indicated category that had appeared in the last list of the trial. An example of a trial in the critical condition looks like this: "* baseball biology dress vulture ! pronoun botany apartment trombone 0517 8733 TYPE OF TRANSPORTATION." During testing, the experimenter typed down subjects' oral responses, and correct rates were later analyzed using the JMP software (SAS Institute Inc.).

Results:

Because the experiment procedure was modified after the first few subjects had already been tested, only 18 bilinguals and 16 monolinguals were included in the final analysis of Experiment 1. A mixed model ANOVA showed a main effect of condition (critical vs. control), with $F(1, 32) = 4.93$, $p = 0.034$, but no main effect of group (bilingual vs. monolingual), with $F(1,32) = 0.76$, $p = 0.389$. Critically, the interaction between group and condition was significant, with $F(1, 32) = 5.68$, $p = 0.023$. After controlling for subjects' SAT scores and their performance in the control condition, the effect of group on subjects' performance in the critical condition remained significant, with $p = 0.028$.

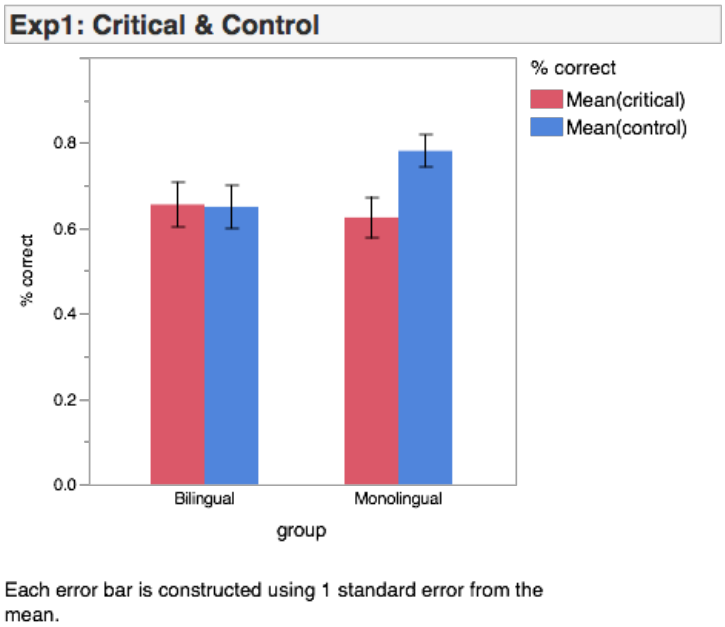
As can be seen from Table 1 and Graph 1, across all conditions, bilinguals and

monolinguals had the same correct rate of 68.8%. Monolinguals performed significantly better in the control condition (two-list trials with no semantic foil) than in the critical condition (two-list trials with a semantic foil in the first list), with a correct rate of 78.1% in the control condition and that of 62.5% in the critical condition. A paired sample t-test found this difference to be significant (M=0.16, SD=0.21), with $t(15) = 3.03$, $p = 0.004$. In comparison, bilinguals showed no significant difference between their performance in the critical and control conditions, with a correct rate of 65.6% in the critical condition and that of 65.0% in the control condition. This difference was not statistically significant (M=0.01, SD=0.19), with $t(17) = 0.12$, $p = 0.451$.

Table 1: Mean items correctly recalled (%) in Exp1

	All	Critical	Control	Difference (Control-Critical)	Filler
Bilingual	0.688	0.656	0.650	-0.006	0.722
Monolingual	0.688	0.625	0.781	0.156	0.672
Total	0.676	0.636	0.692	0.056	0.688

Graph 1: Subjects' performance in the critical and control conditions in Exp1



Discussion:

To recap, the aim of Experiment 1 was to examine whether bilinguals' heightened executive functions enhanced their performance in working memory tasks that had high inhibitive control demands. If the hypothesis was true, we should see bilinguals outperforming monolinguals in the two-list critical condition in which they needed to inhibit the distraction from the first list and correctly recall the items from the second list. No difference was expected between bilinguals' and monolinguals' performance in the two-list control condition or in the one-list filler trials.

From the analysis, we can see that monolingual subjects performed significantly worse when there was a semantic foil present than when there wasn't, showing a definite proactive interference effect, which corresponds with the results in the Tehan & Humphreys (1995) study. Bilinguals, on the other hand, were unaffected by the presence or absence of a semantic foil. The significant group-condition interaction further proves that there is a difference between bilingual and monolingual subjects' reaction to task-irrelevant but distracting information within a working memory task. The fact that an effect of group on the size of the interference effect is still present after controlling for SAT scores shows that this difference is most probably caused by the difference in language experience instead of general cognitive abilities.

While within-group comparisons show that bilinguals are indeed better than monolinguals at suppressing distractions within a working memory task with high cognitive control demand, between-group comparisons do not show a significantly higher correct rate

for bilinguals within the high-conflict (critical) condition. This could be due to a relatively small sample size, but could also have to do with subjects' lower verbal and vocabulary skills, as well as the potential interference from their co-activated off-line language, as is also hypothesized in this study. Overall, results from Experiment 1 provided support to the hypothesis that bilinguals show less interference than monolinguals in working memory tasks with a high cognitive control demand.

Experiment 2

Rationale:

Previous research on bilinguals' parallel language activation has found that subjects' performance in language comprehension or production tasks could be weakened when there is phonological or semantic disagreement between the tested and untested language (Costa, Roelstraete, & Hartsuiker, 2006). In this experiment, I am using the phenomenon of the phonological similarity effect to study bilinguals' working memory performance in a high verbal demand working memory task.

The phonological similarity effect is a prominent finding in the field of working memory. It refers to the fact that phonologically similar words and the order in which they are presented are generally harder to remember than phonologically dissimilar ones (Conrad & Hull, 1964; Baddeley, 1966; Wickelgren, 1965; Conrad, 1965). This means that a list of similar-sounding words like "cat," "hat," "mat," etc. will be harder to recall than a list of dissimilar words like "hay," "sea," and "ball." The phonological similarity effect is robust, and has been replicated across various studies using both visual (Baddeley, 1968) and

auditory (Longoni, Richardson, & Aiello, 1993) presentations of words (Baddeley, 1966) and pictures (Hitch & Halliday, 1983). Since bilinguals always have both languages activated, Experiment 2 aims to find out whether Spanish-English bilinguals will also show impaired performance when the tested English words are not similar-sounding, but their Spanish translations are.

Material:

Experiment 2 tested subjects in a simple span wordlist recall task with four conditions, each condition containing 12 lists of 6 words[1]. Condition 1 contained words that are phonologically similar in English; condition 2 contained the same words as condition 1, but arranged in a way so that words in each list were phonologically dissimilar; condition 3 contained words that were phonologically similar in Spanish but not English; and condition 4 contained the same words as condition 3, but rearranged so that the Spanish translations of words in each wordlists were phonologically dissimilar. All stimuli were presented in English, so only condition 1 contained words that appeared to be phonologically similar on the surface.

To ensure that the material was well chosen and that a phonological similarity effect would indeed be observed, two pilot tests were conducted before the study was run. Five English monolinguals were tested on the English version of the pilot test, which had the same procedure as Experiment 2, but only contained lists from conditions 1 and 2. Subjects' average performance (percent of items correctly recalled in the right position) was 57.2% for

[1] For the first 6 subjects tested (4 monolingual, 2 bilingual), there was an error in the script which resulted in the repetition of a trial in condition 2. The performance of these 6 subjects in the second repeated trial was excluded from analysis.

condition 1 (SD=0.68), and 70.0% for condition 2 (SD=0.70), which was a 12.8% difference between conditions. Since condition 1 contained phonologically similar words and condition 2 phonologically dissimilar ones, subjects' poorer performance in condition 1 than in condition 2 shows that the material in these two conditions did produce a reliable phonological similarity effect.

Similarly, four Spanish-English bilinguals were tested on the Spanish version of the pilot test, which also had the same procedure as Experiment 2, but only contained the Spanish translations of wordlists in conditions 3 and 4. Subjects' average performance (percent of items correctly recalled in the right position) was 45.8% for condition 3 (SD=0.67), and 55.9% for condition 4 (SD=0.14), which was a 10.1% difference between conditions. Since condition 3 contained phonologically similar words in Spanish and condition 4 phonologically dissimilar ones, subjects' poorer performance in the Spanish version of condition 3 than in the Spanish version of condition 4 showed that the Spanish translations of material in these two conditions also produced a reliable phonological similarity effect. All subjects tested in the pilot tests reached the criteria for being either monolingual or bilingual, and did not participate again in the actual study.

Procedure:

All stimuli were presented in the same testing session as Experiment 1, on a computer using the PsyScope software. Two scripts were created with wordlists from all four conditions semi-randomly mix so that in both scripts there would be at least two phonologically dissimilar wordlists (from conditions 2, 3, and 4) presented in between two

phonologically similar wordlists (from condition 1). At the beginning of each trial, an asterisk ("*") was shown for 2 seconds, after which each word in the given list was presented individually for one second on the screen. Immediately after all the words were presented, subjects saw a slide that instructed them to recall the words they have just seen in the same order that they saw them, at which point subjects would type their responses into an excel worksheet on a small laptop set in front of the bigger test computer. Subjects were told to either take a guess or leave the position blank if they could not remember a word. Subjects were given as much time as they needed to complete recall for each trial. Responses were coded by the experimenter, and the percentages of items recalled in the correct position were analyzed in JMP.

Results:

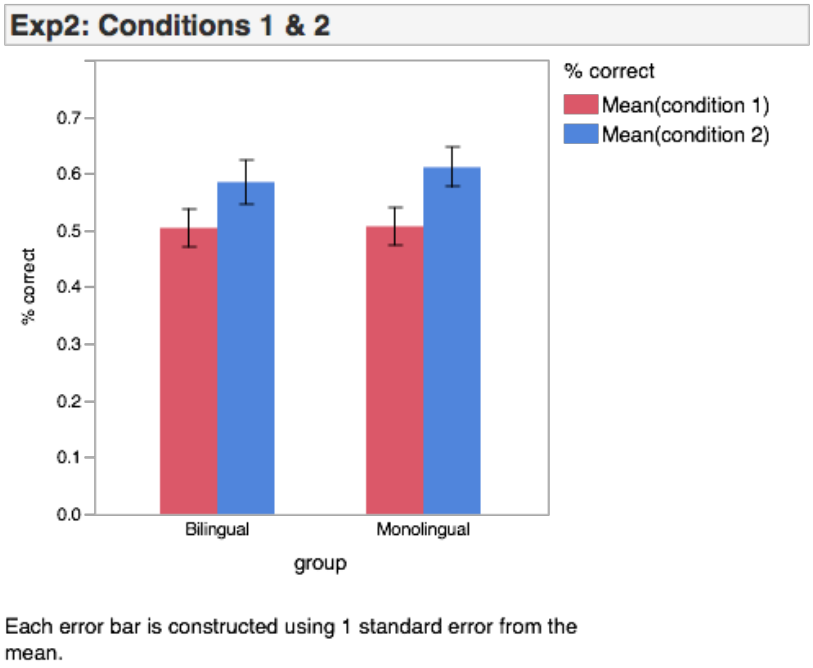
Across all conditions, the average correct items recalled in position for bilinguals was 63.5%, which is comparable with the 64.4% for monolinguals. For conditions 1 and 2, mixed model ANOVA found an overall significant difference between performance in conditions 1 and 2, with $F(1, 38) = 28.34$, $p < 0.001$. No significant effect was found for group, with $F(1, 38) = 0.100$, $p = 0.753$, nor for the interaction between group and condition, with $F(1, 38) = 0.45$, $p = 0.506$. As can be seen in Table 2 and Graph 2, both bilinguals and monolinguals performed better in condition 2 than in condition 1. Monolinguals had a correct rate of 61.1% in condition 2, much higher than the 50.7% in condition 1. A paired sample t-test showed that this difference was significant ($M=0.10$, $SD=0.12$), with $t(19) = 3.96$, $p < 0.001$. Bilinguals had a correct rate of 58.5% in condition 2, also higher than their

performance of 50.4% in condition 1. This difference is also statistically significant (M=0.08, SD=0.10), with t(19) = 3.56, p = 0.001.

Table 2: Mean items correctly recalled in position (%) by group and condition in Exp2

	All	C1	C2	Difference (C2-C1)	C3	C4	Difference (C4-C3)
Bilingual	0.635	0.504	0.585	0.081	0.710	0.742	0.033
Monolingual	0.644	0.507	0.611	0.104	0.703	0.757	0.054
Total	0.632	0.506	0.598	0.092	0.706	0.750	0.043

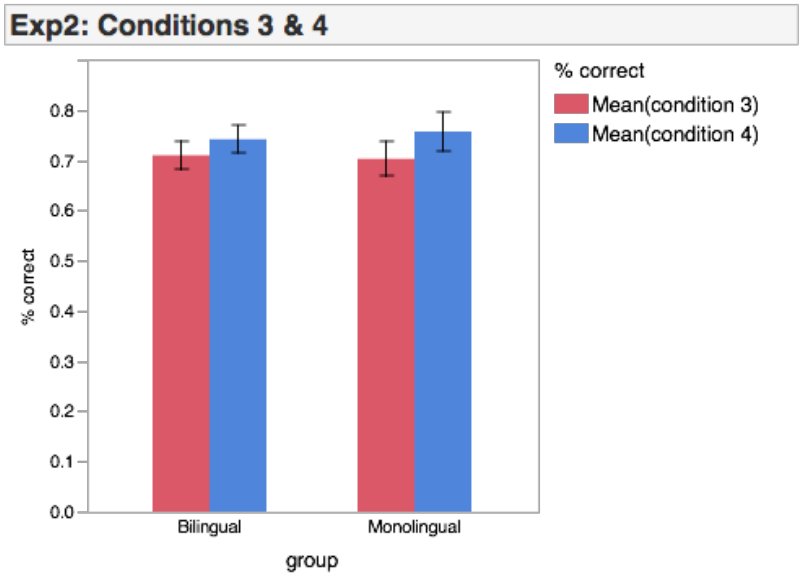
Graph 2: Subjects' performance in conditions 1 and 2 in Exp2



For conditions 3 and 4, mixed model ANOVA found an overall higher performance in condition 4 than in condition 3, with F(1, 38) = 13.28, p < 0.001. There was no significant effect of group, with F(1, 38) = 0.01, p = 0.926. The group by condition interaction was also not significant, with F(1, 38) = 0.88, p = 0.353. Paired-sample t-tests found significant differences between conditions for both groups. Monolinguals had a difference of M=0.05, SD=0.09; t(19) = 2.84, p = 0.005. Bilinguals had a difference of M=0.03, SD=0.06; t(19) = 2.37, p = 0.014. Graph 3 shows a comparison of the performance of bilinguals and

monolinguals in conditions 3 and 4.

Graph 3: Subjects' performance in conditions 3 and 4 in Exp2



Discussion:

Experiment 2 examined the hypothesis that bilingual parallel language activation affected bilinguals' working memory performance in verbal tasks. Based on robust findings of the phonological similarity effect, both bilinguals and monolinguals were expected to perform worse in the English similar condition (condition 1) compared to the English dissimilar condition (condition 2). If the parallel language hypothesis was correct and parallel language activation did affect verbal working memory performance negatively, we expected to see bilinguals performing worse in the Spanish similar condition (condition 3) compared to the Spanish dissimilar condition (condition 4), indicating that the Spanish translation was automatically activated. Monolinguals should not have shown a difference in performance for conditions 3 and 4.

The results showed that both bilinguals and monolinguals were affected by the phonological similarity effect when it was presented in the tested language (English), which corresponds with previous literature. However, while an overall statistically significant effect was seen between conditions 3 and 4, the data actually showed a larger difference for monolinguals than for bilinguals in their performance in these two conditions, which could not be explained by parallel language activation, since English monolinguals were not supposed to be affected by phonological similarity in Spanish. In addition, no significant difference was found for the group-condition interaction. One possibility why we are seeing a significant difference between conditions 3 and 4 might be because of inadvertent differences between the lists in conditions 3 and 4. That is, the selection of items into lists in condition may have made those in condition 3 slightly easier because of strategies that subjects might have employed. One example of such strategies is to combine the meaning of all the words in each trial to form a story, in which case subjects might be affected by the particular order in which words appeared in each condition. Although preliminary analysis has found no outlier list in which subjects performed either particularly well or badly in, more analysis will be done to determine whether some lists show any properties that might have aided subjects' recall.

Because no significant difference was found between bilinguals' performance in conditions 3 and 4 and that of monolinguals', it is possible that parallel language activation for bilinguals does not have a robust effect on verbal working memory performance. However, more subjects should be tested, and error types should be analyzed in each

condition before a definite conclusion can be given. The fact that this task used all English materials, and was delivered in an all-English context might have also led to this lack of effect. Since on average bilingual subjects rated themselves as more proficient in English than in Spanish, it is possible that any interference from their less-dominant Spanish would be fairly weak when they are engaging in English only. Future studies might want to test bilingual subjects in their less-dominant language instead in order to observe stronger interference from their other language. Overall, Experiment 2 has provided no support for the hypothesis that parallel language activation negatively affects bilinguals' performance in high verbal demand working memory tasks.

General Discussion

While bilingualism is widely believed to enhance executive functions, its effect on working memory is less clear. However, the mixed research results could be explained by bilingualism affecting specific aspects of working memory differently. By testing bilinguals' performance in inhibiting distractions and the potential phonological similarity effect of the unsolicited language, the current study investigated how bilingualism might boost working memory performance through enhanced executive control and hurt it through parallel language activation. In Experiment 1, while between-group comparison did not find bilinguals outperforming monolinguals in the high-conflict condition in terms of overall level of performance, within-group comparison shows a clear bilingual advantage in the inhibition of distracting information in a working memory task. This finding supports the hypothesis that bilingualism positively affects subjects' working memory performance through

enhancing their executive functions. Because no previous study has tested bilinguals' proactive inhibition in a working memory task using directed forgetting, the result from Experiment 1 is an important addition to the existing literature.

In Experiment 2, although bilinguals were found to have worse recall for list items that were phonologically similar in Spanish than when they were phonologically dissimilar, because this same difference was also found in monolinguals, the result cannot be attributed to the interference from the activated non-response language. Therefore, experiment 2 provides no support for the hypothesis that interference from parallel language activation negatively affects bilinguals' performance in verbal working memory tasks. Future studies should look into whether the language context of the task and bilinguals' own language dominance play a role in determining the existence or strength of possible interference from parallel language activation in verbal working memory.

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