Order Effects in Bilingual Recognition Memory Partially Confirm Predictions of the Frequency-Lag Hypothesis

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Abstract

The present study examined task order, language, and frequency effects on list memory to investigate how bilingualism affects recognition memory. In Experiment 1, 64 bilinguals completed a recognition memory task including intermixed high- and medium-frequency words in English and another list in Spanish. In Experiment 2, 64 bilinguals and 64 monolinguals studied lists with only high-frequency English words and a separate list with only low-frequency English words, in counterbalanced order followed by a recognition test. In Experiment 1, bilinguals who completed the task in the dominant-language first outperformed bilinguals tested in the nondominant-language first, and order effects were not stronger in the dominant language. In Experiment 2, participants who were tested with high-frequency word lists first outperformed those tested with low-frequency word lists first. Regardless of language and testing order, memory for English and high-frequency words was lower than memory for Spanish and medium-frequency (in Experiment 1) or low-frequency (in Experiment 2) words. Order effects on recognition memory patterned differently from previously reported effects on picture-naming in ways that do not suggest between-language interference and instead invite an analogy between language dominance and frequency of use (i.e., dominant language = higher frequency) as the primary factor affecting bilingual recognition memory.

Keywords: bilingualism, list memory, list composition, frequency effects, testing order

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When they are speaking in just one language bilinguals do not seem obviously different from monolinguals. However, by definition bilinguals inevitably have to switch languages depending on the context and with whom they are speaking e.g., bilinguals might start the morning speaking one language and then switch to another language when they arrive at school or at work. Bilinguals also use each language less frequently than monolinguals. According to the Frequency-Lag hypothesis (a.k.a. the Weaker Links hypothesis; Gollan, et al., 2005; Gollan, Montoya, Cera, & Sandoval, 2008; 2011; Gollan & Silverberg, 2001), bilinguals encounter words in each language less often than monolinguals because by virtue of speaking two languages, and only speaking one language at a time, bilinguals divide frequency of use between their two languages. By contrast, monolinguals use one language all the time, thereby likely using that language more frequently than bilinguals use each one of their two languages. The Frequency-Lag hypothesis was inspired by findings that bilinguals are disadvantaged in linguistic tasks relative to monolinguals[1]. Though numerous studies investigated these disadvantages, few studies examined verbal memory in bilinguals, particularly with respect to possible effects of a language switch (across testing blocks), and word frequency. The present study aimed to fill this gap.

Importantly, differences between bilinguals and monolinguals arise even when bilinguals are tested in their dominant (Gollan et al., 2005; Gollan, Montoya, Cera, & Sandoval, 2008;

[1] Bilinguals show reduced category fluency (Gollan, Montoya, & Werner, 2002; Rosselli, Ardila, Araujo, Weekes, Caracciolo, Padilla, & Ostrosky-Solís, 2000; Portocarrero, Burright, & Donovick, 2007), slower word recognition (Ransdell & Fischler, 1987; but see Gollan, Slattery, Goldenberg, Van Assche, Duyck & Rayner, 2011), slower and less accurate picture-naming responses (Gollan, Montoya, Fennema-Notestine, & Morris, 2005; Gollan & Silverberg, 2001; Gollan, Fennema-Notestine, Montoya, & Jernigan, 2007; Roberts, Garcia, Desrochers, & Hernandez, 2010), and bilinguals also have smaller receptive vocabularies (Bialystok, Luk, Peets, & Yang, 2010; Luk & Bialystok, 2012).

Gollan et al., 2011) and first-learned language (Ivanova & Costa, 2008). Thus, the processing costs associated with bilingualism do not simply reflect failure to test bilinguals in whichever language is most proficient. Particularly suggestive of a Frequency-Lag effect, the bilingual disadvantage in picture naming is bigger for low frequency targets (Gollan et al., 2008; Ivanova & Costa, 2008), and bilinguals also exhibit larger frequency effects in the nondominant than in the dominant languages (Cop, Keuleers, Drieghe, & Duyck, 2015; Duyck, Vanderelst, Desmet, & Hartsuiker, 2008; Gollan et al., 2008). This implies that not only do bilinguals lag behind monolinguals in frequency of use, but within bilinguals the nondominant language also lags behind the dominant language in frequency of use.

In picture naming, high frequency words are accessed more quickly than low frequency words. In memory for lists of words, word frequency has opposite effects on recognition and recall. This pattern is often referred to as the *word frequency paradox* (Gillund & Shiffrin, 1984; Mandler, Goodman, & Wilkes-Gibbs, 1982). When participants were asked to recall a recently presented list of words, they recalled fewer low-frequency words than high-frequency words, but the opposite was true for recognition (Gillund & Shiffrin, 1984). This effect of word frequency on recognition memory is counterintuitive; low-frequency words are associated with both a lower false alarm rate and higher hit rate (and, therefore, a higher d') compared to high-frequency words, a pattern known as the *mirror effect* (Glanzer & Adams, 1985). Combining the assumptions of the Frequency-Lag Hypothesis, and the mirror effect findings, bilinguals should be disadvantaged in free recall relative to monolinguals, but advantaged in recognition, especially in the nondominant language.

Confirming this prediction, in free recall, bilinguals recalled fewer items, exhibited worse memory for item order, and weaker primacy effects in the nondominant than the dominant language (Francis & Baca, 2014; Yoo & Kaushanskaya, 2016; Francis, Artega, Liaño, & Taylor, 2020)[2]. In addition, two studies reported better recognition memory for words in bilinguals' nondominant than their dominant language (Francis & Gutiérrez, 2012; Francis & Strobach, 2013). In some comparisons, bilinguals also showed better recognition memory than monolinguals, but this varied by language dominance groups; Spanish-dominant Spanish-English bilinguals outperformed Spanish speaking monolinguals in both languages, but English-dominant Spanish-English bilinguals exhibited worse recognition memory performance in both languages relative to English speaking monolinguals. Interpretation of these comparisons was further complicated by the fact that monolinguals in this study completed list memory tasks with full attention or under cognitive load in counterbalanced order, while bilinguals completed the tasks in English and Spanish (with full attention) in counterbalanced order – and order effects were not examined.

In picture naming tasks, bilinguals perform worse in their dominant language if they are first tested in their nondominant language (e.g., Branzi, Martin, Abutalebi, & Costa, 2014; Van Assche, Duyck, & Gollan, 2013; Kroll et al., 2008; Misra, Guo, Bobb, & Kroll, 2012). Speech production requires bilinguals to select names for response in just one language and prior activation of the nondominant language might increase between-language interference upon returning to the dominant language. Specifically, when completing a task in the nondominant language bilinguals might globally inhibit dominant language, and release of such inhibition might take sufficient time to elicit a disadvantage after switching to the dominant language (Branzi et al., 2014; Wodniecka, Szewczyk, Kalamala, Mandera, & Durlik, 2020; Misra et al.,

[2] Consistent results have been found in bilingual memory for expository texts, similar to those typically encountered in academic settings. Bilinguals recalled less information in their nondominant language relative to their dominant language. However, the same participants performed at the same level on recognition memory tests in both languages (Vander Beken & Brysbaert, 2017; Vander Beken, Woumans, & Brysbaert, 2017).

2012). In recognition memory the opportunity for similar between-language interference might be smaller because the task that itself provides the linguistic material (bilinguals do not have to produce the words, they are presented). However, language of testing order could nevertheless influence patterns of performance.

Task order effects have been examined in the memory literature by considering memory for lists with high frequency versus low frequency words and revealed notably different effects on recognition versus recall (Gillund & Shiffrin, 1984). In free recall, frequency effects are fragile; they are robust when lists are blocked by frequency (all high frequency or all low frequency words) but are decreased or even eliminated when high- and low-frequency words are inter-mixed in a study list (e.g., Gregg, 1976). Similarly, bilinguals recalled words in the dominant language better than the nondominant language unless the study lists intermixed words from both languages (Nott & Lambert, 1968; Gregg, 1976). By contrast, frequency effects in recognition memory are highly robust regardless of list composition, making recognition a stronger candidate for investigation of how language of testing order might affect memory in bilinguals.

To determine the possible effects of bilingualism on verbal memory we investigated task order and frequency effects on recognition memory for word lists. In Experiment 1 we tested bilinguals in both languages, and in Experiment 2 we tested bilinguals and monolinguals in English only. We hypothesized that bilinguals might recognize fewer words in their dominant language after first completing the task in the nondominant[3] language, and vice versa. In Experiment 2, we further examined the possible cognitive mechanism underlying testing-order effects by asking if order of testing with high- vs. low-frequency words in English only

[3] Note that although bilinguals in the present study learned Spanish first and English second, they were English-dominant because of extended immersion in English and schooling primarily in English (see Table 1).

influenced recognition memory in bilinguals' in their dominant language, and in monolinguals in their only language.

Experiment 1

Methods

Participants

Sixty-four Spanish-English bilinguals from UC San Diego participated for course credit. One participant was excluded for failing to follow instructions. Participant characteristics are shown in Table 1; bilinguals tested in English-first did not differ significantly from bilinguals tested in Spanish-first in any self-reported characteristic, or picture naming scores in either language (all *p*s ≤ 0.22). A power analysis was performed for sample size estimation, based on data from Francis and Strobach (2013) involving 64 participants (32 Spanish dominant and 32 English dominant bilinguals) comparing dominance group, word language, and frequency in a mixed ANOVA. The effect size in this study was 0.18, considered to be medium-small according to Cohen's (1992) criteria. With an alpha = .05 and power = 0.80, the projected sample size needed to observe a group by language interaction with this effect size calculated using G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009), is approximately 44.

[Table 1 near here]

Materials

A set of high frequency (HF) and medium frequency (MF) words in English (240 words; 120 HF and 120 MF) and their Spanish translation equivalents were used as targets and lures (we avoided low frequency words which bilinguals might not know in their nondominant language) (see Appendix A for a list of the stimuli). English words were generated using the English Lexicon Project (Balota et al., 2007) based on a specified frequency range for each category (medium: 48-113 times per million, high: > 114 times per million). To show comparable word frequencies for words in English and Spanish we compared frequencies using the SUBTLEX-US and SUBTLEX-ESP databases which include word frequency estimates obtained from films and television subtitles (Brysbaert & New, 2009; Cuetos, Glex-Nosti, Barbón, & Brysbaert, 2011) (Table 2).

Each participant saw two separate lists (1) 120 words in English (60 targets – 30 HF, 30 MF; 60 lures – 30 HF, 30 MF) and (2) 120 words in Spanish (60 targets – 30 HF, 30 MF; 60 lures – 30 HF, 30 MF). For each participant words were randomly chosen (from the 240 words) to serve as study words. Each participant saw each word in either English or Spanish only once.

[Table 2 near here]

Procedures

There were two experimental blocks each consisting of a study phase followed by a recognition memory task, presented in either English or Spanish first. List order (English list first vs. Spanish list first) was counterbalanced across participants, so that half would complete the task in English first, and half in Spanish first. In the study phase, participants were instructed to study the words on the computer screen. Study words were displayed for 1.5s each. In each block, participants studied a total of 60 words, 30 HF and 30 MF words presented in random order, one at a time in the center of the screen, using the PsychoPy software (Peirce, 2007) on an iMac 7 computer with a 20-inch color monitor. Following the study phase, participants were given a 1-minute nonverbal distractor task (a 7-piece wooden tangram puzzle), in which they were given 10s to study the puzzle and after 10s the puzzle pieces were shuffled, and participants were given 1 minute to put the puzzle pieces back together. This task was administered to minimize the effect of working memory on recognition performance. Following the distractor task, the recognition test was presented. This test consisted of the 60 target words from the study phase randomly intermixed with the remaining 60 words from the set of words as lures. Each word was presented one at a time for an old-new recognition decision. Participants provided a confidence rating for each judgement on a 1 to 6 rating scale (1 = 100% sure the item was not in the study list, 6 = 100% sure the item was in the study list).

After completing the first experimental block, participants filled out a language history questionnaire followed by the second recognition memory task (in whatever language they had not yet completed). Once both experimental blocks were completed, participants were asked to spontaneously recall as many words as they could from both study lists. Participants were given 5-minutes to write down as many words they could remember in each language from *both* study phases. Participants were not warned in advance that there would be a recall phase at the end; results from the recall task exhibited better recall for whatever list was studied last, and will not be reported in detail. Following the recall task, they completed a translation matching task (which was at ceiling for most participants) and the Multilingual Naming Task (MINT), which is a picture naming test that provides an objective measure of language proficiency (Gollan, Weissberger, Runnqvist, Montoya, & Cera, 2012; Tomoschuk, Ferreira, & Gollan, 2018).

Results

The main results are summarized in Figure 1, with details presented in Table 3. Bilingual recognition memory performance (d') was analyzed using a 2x2x2 ANOVA, with list order (English-first vs. English-second) as a between-subject factor, word frequency (high vs. medium) and language (Spanish vs. English) as within-subject factors. Bilinguals who completed the recognition memory task in English first recognized more words overall than bilinguals who completed the task in Spanish first, $F(1, 61) = 7.22$, $p = 0.009$, $MSE = 1.322$, $\eta_p^2 = 0.106$.

Consistent with previous studies and the Frequency-Lag hypothesis, participants recognized more words in Spanish (the nondominant language) than English (the dominant language), a main effect of language $F(1, 61) = 14.95$, $p = 0.0003$, $MSE = 0.573$, $\eta_p^2 = 0.197$, and medium frequency words better than high frequency words, a main effect of frequency, $F(1, 61) = 84.58$, $p < 0.0001$, $MSE = 0.154$, $\eta_p^2 = 0.580$. All other main effects and interactions were not significant, all ps ≥ 0.111.

To further examine language of testing order effects we conducted separate 2x2 ANOVAs for each language. In English, the dominant language, bilinguals recognized medium frequency words better than high frequency words, a main effect of frequency, $F(1, 61) = 43.49$, $p < 0.0001$, $MSE = 0.145$, $\eta_p^2 = 0.416$, and language of testing order effects were marginally significant; bilinguals who were tested in English first tended to exhibit better recognition memory for English words than bilinguals who were tested in Spanish first, a marginal main effect of list order, $F(1, 61) = 2.80$, $p = 0.09$, $MSE = 1.16$, $\eta_p^2 = 0.044$. There was no interaction between language of testing order and frequency, $p = 0.60$. In Spanish, the nondominant language, bilinguals recognized medium frequency words better than high frequency words, a main effect of frequency, $F(1, 61) = 39.81$, $p < 0.0001$, $MSE = 0.170$, $\eta_p^2 = 0.395$, and language of testing order effects were highly robust; bilinguals tested in English first better recognized Spanish words than bilinguals tested in Spanish first, $F(1, 61) = 8.99$, $p = 0.004$, $MSE = 0.731$, $\eta_p^2 = 0.129$. Additionally, bilinguals tested in English first tended to exhibit a larger frequency effect within Spanish than those tested in Spanish first, a marginally significant interaction between language of testing order and word frequency, $F(1, 61) = 2.86$, $p = 0.095$, $MSE = 0.17$, $\eta_p^2 = 0.044$.

[Table 3 near here]

[Figure 1 near here]

Discussion

In Experiment 1, we investigated word frequency effects on recognition memory in Spanish-English bilinguals for words in English and Spanish with half completing the task in English first, and half in Spanish first. Of interest, bilinguals who completed the task in the dominant language (English) first outperformed those who completed the task in the nondominant language (Spanish) first. However, language of testing order effects only partly followed expectations based on studies of bilingual language production. Matching these expectations, bilinguals who were tested in the nondominant language first exhibited worse performance than bilinguals tested in the dominant language first. However, unlike picture naming studies, in which previous studies showed testing order primarily affected the dominant language, there was no significant interaction with language of testing, and if anything, testing order effects were more robust in Spanish, the nondominant language than they were in English, the dominant language. To further investigate the nature of testing order effects, in Experiment 2 we considered if order effects are specific to language membership or if they might be driven by frequency of use by testing bilinguals in English only, with high frequency or low frequency word lists administered first or second. We also asked if order effects are specific to bilinguals by testing monolinguals in the same protocol.

Experiment 2

To understand the nature of order effects in recognition memory, in Experiment 2 bilinguals and monolinguals studied lists of high or low frequency English words presented first or second (high-frequency list first vs. low-frequency list first). If the order effects observed in Experiment 1 primarily reflected language membership independent of frequency, then we should find no order effects on recognition memory in Experiment 2. However, if the order effects reflected a different underlying mechanism, and one not specific to bilingualism, these could be found in bilinguals and monolinguals alike. For example, assuming Spanish words in Experiment 1 should simply be considered lower frequency words (for the English-dominant bilinguals tested in the present study), we might expect participants who were presented with low-frequency word lists first would exhibit worse recognition memory than those who were presented with high frequency word lists first.

Methods

Participants

We used the same effect size and procedure to calculate sample size as in Experiment 1. Sixty-four Spanish-English bilinguals and 64 monolinguals from UC San Diego participated in the experiment for course credit. One bilingual was excluded for not following study instructions. Participant characteristics are shown in Table 1.

Materials

A set of high frequency (HF) and low frequency (LF) words in English (240 words; 120 HF and 120 LF) (see Appendix B for a list of the stimuli). The HF words used in this study were the same as those in Experiment 1. Similar to Experiment 1, the LF words were generated using the English Lexicon Project (Balota et al., 2007) based on a specified frequency range (low: < 72 times per million). Frequency values from the SUBTLEX-us corpus are shown in Table 1 (Brysbaert & New, 2009).

Each participant received two separate lists (1) 120 HF words (60 targets, 60 lures) and (2) 120 LF words (60 targets, 60 lures). For each frequency list words were randomly chosen (from the 120 words) to serve as study (i.e., target) words. Each participant saw each word only once.

Procedures

Procedures were identical to those of Experiment 1. There were two experimental blocks in this experiment, each consisting of a recognition memory task, presenting either high or low frequency words first. List order (HF list first vs. LF list first) was counterbalanced across participants, so that half would complete the task with HF words lists presented first, and half with LF words presented first.

Results

The results are summarized in Figure 2, with additional details presented in Table 4. Recognition memory performance (*d'*) was analyzed using a 2x2x2 ANOVA with participant group (bilinguals vs. monolinguals) and list order (High frequency first vs. High frequency second) as between-subjects factors, and word frequency (high vs. low) as a within-subjects factor. As in Experiment 1, participants recognized low frequency words better than high frequency words, a robust main effect of frequency, $F(1, 123) = 48.25$, $p < 0.0001$, $MSE = 0.248$, $\eta_p^2 = 0.282$. Most interestingly, order effects were significant only for low frequency words; participants recognized low frequency words best when high frequency words were presented first, a significant interaction between word frequency and list order, $F(1, 123) = 5.91$, $p = 0.016$, $MSE = 0.248$, $\eta_p^2 = 0.046$. All other main effects and interactions were not significant, all *p*s ≥ 0.288.

Follow-up 2x2 ANOVAS were used to evaluate order effects within bilinguals and monolinguals alone. Consistent with the literature, monolinguals showed higher recognition memory for low frequency words than high frequency words, a robust main effect of frequency

$F(1, 62) = 18.91$, $p < 0.0001$, $MSE = 4.97$, $\eta_p^2 = 0.233$, but order effects were not significant, $F = 0.221$, $p = 0.64$, and there was no significant interaction, $F(1, 62) = 1.44$, $p = 0.234$, $MSE = 0.38$, $\eta_p^2 = 0.022$. Bilinguals also recognized low frequency words better than high frequency words, a robust main effect of frequency, $F(1, 61) = 30.48$, $p < 0.0001$, $MSE = 7.11$, $\eta_p^2 = 0.333$, but bilinguals who were presented with low frequency English words first exhibited better recognition memory for low-frequency words than bilinguals who were presented with high frequency words first, a significant interaction between frequency and list order, $F(1, 61) = 5.19$, $p = 0.026$, $MSE = 1.21$, $\eta_p^2 = 0.078$. As in Experiment 1, in Experiment 2, participants tested in different orders were matched, with two exceptions which if anything should have disadvantaged the groups that performed better (see Table 1).

[Table 4 near here]

[Figure 2 near here]

Discussion

Experiment 2 revealed significant testing order effects that paralleled those reported in Experiment 1. Specifically, in Experiment 2 recognition memory for low-frequency words (like memory for Spanish words in Experiment 1), exhibited testing order effects with improved recognition memory when preceded by testing with higher frequency word lists (like testing in English first in Experiment 1). Although list order did not significantly affect recognition memory in monolinguals alone, the results trended in the same direction, and the interaction between participant type and list order effects did not approach significance.

General Discussion

The present study revealed a number of key results. First, replicating previous studies, participants recognized low-frequency words better than high frequency words. Frequency effects were highly robust in both Experiments 1 and 2, and they were significant in English and in Spanish, and in bilinguals and monolinguals, in both cases regardless of order effects. Second, replicating work by Francis and colleagues (Francis & Gutiérrez, 2012; Francis & Strobach, 2013), bilinguals recognized words in Spanish (the nondominant language) better than words in English (the dominant language). New to the present study, language dominance effects on recognition memory were significant regardless of language of testing order, and we identified two significant testing order effects. In Experiment 1, bilinguals tested in English first (the dominant and we hypothesize "higher frequency language" for these bilinguals) exhibited better recognition memory than bilinguals tested in Spanish first. These order effects did not interact significantly with language and were robust in Spanish alone (the "lower frequency language"), and marginal in English alone. Experiment 2 also revealed significant order effects, with memory for low-frequency words being significantly better in participants who were first tested with high frequency lists. Order effects were robust in bilinguals alone, but not in monolinguals alone, though numerically monolinguals seemed to exhibit effects in the same direction as bilinguals, and the interaction between participant type and testing order did not approach significance. Also matching results reported by Francis and Strobach (2013), the English-dominant bilinguals tested herein exhibited equivalent recognition memory for English words relative to English speaking monolinguals.

Explaining Order Effects

The investigation of order effects was motivated by studies of picture naming (e.g., Branzi et al., 2014), and verbal fluency tasks (e.g., Van Assche, et al., 2013) which revealed worse performance in the dominant language after first completing the task in the nondominant language. The results of the present study can be described in the same way, but the similarity of results across picture-naming vs. recognition memory tasks ends there. Though recognition memory was worse for bilinguals who completed the task in Spanish first, order appeared to affect both languages, not just the dominant language (and if anything order tended to affect the nondominant language more than the dominant language – the opposite of what was found in picture naming and verbal fluency studies (Misra et al., 2012; Van Assche et al., 2013; Wodniecka et al., 2020)). Importantly, bilinguals tested in English-first did not differ from bilinguals tested in Spanish-first in language history, bilingual proficiency, or demographic variables (see Table 1), thus the observed differences could not simply be attributed to mismatching across groups. Similarly, testing-order affected recognition memory for low-frequency, but not high-frequency word lists in Experiment 2. In studies on bilingual speech production, order effects were explained as lingering effects of speaking the nondominant language interfering with retrieval of words in the dominant language (either because the nondominant language remains active and therefore is better able to compete for selection, or because the dominant language was inhibited when bilinguals spoke in the nondominant language). Since recognition memory tasks do not require bilinguals to speak in either language, and given that order effects did not affect the dominant language more than the nondominant language, it seems unlikely that the order effects we found could be explained in a similar way.

Further research will be needed to identify the cognitive mechanism underlying order effects on recognition memory, but order effects could perhaps reflect a strategic response to task-difficulty. Considering that high-frequency words are *more difficult* to recognize than low-frequency words, bilinguals who completed the task in English first, and participants who were first tested with high-frequency words in English alone, maybe have noticed upon recognition testing that they did not perform as well as they might have – leading to greater efforts and better performance upon subsequent testing with Spanish (in Experiment 1) or lower-frequency English words (in Experiment 2). This way of explaining order effects implies conscious strategic effort, but a similar effect could have emerged without conscious awareness. Critically, such an explanation could easily affect bilinguals and monolinguals alike. Note however that this account is speculative, and a priori we might arguably have expected the opposite. For example, completing an easier task first (Spanish, low-frequency English lists) could have led to better performance on the subsequent more difficult task (English, high-frequency English lists) in the same way that skiers are advised to warm up on green or blue runs before they hit the black runs, and gymnasts are taught to do single back flips before they attempt doubles.

Also, not clear is why order effects appeared to be somewhat more robust for Spanish than English in Experiment 1, and for bilinguals than monolinguals in Experiment 2 - although these interactions were not significant, it is important to note that the Frequency-Lag Hypothesis might have predicted significant interactions in both cases. Importantly, it is impossible to know how strong the "frequency manipulation" was when comparing English to Spanish in Experiment 1, and bilinguals to monolinguals in Experiment 2. In the latter, order effects might be expected to be more robust in bilinguals if the frequency manipulation is effectively stronger in bilinguals than monolinguals (because of between-group differences in frequency of use). Consistent with this possibility it is perhaps notable that medium frequency English words seemed to exhibit more robust order effects than high frequency English words (in Experiment 1; see Table 2). The interaction between order and language might be more robust if lower frequency words were included in Experiment 1. These speculations will need to be tested in additional work with larger groups of bilinguals with varying proficiency levels, and frequency of use patterns.

Bilinguals vs. Monolinguals (Group Comparisons)

In some ways the results we obtained fit the predictions of the Frequency-Lag Hypothesis, e.g., English-dominant bilinguals exhibited better memory for Spanish than for English words. However, bilinguals did not recognize English words better than monolinguals ($F < 1$, $p > 0.05$) even though bilinguals reported using English less frequently than monolinguals (see Table 1). The presence of a bilingual advantage for Spanish-dominant but not English-dominant bilinguals in Francis and Strobach (2013), and the absence of a bilingual advantage in the present study combined with robust language dominance effects on recognition memory in both studies (and in Francis & Gutiérrez, 2012) fits a general pattern whereby language dominance effects within bilinguals are more consistent than between group effects. That is, bilinguals consistently perform recognition memory tasks better in their nondominant than in their dominant language (in the present study, and in Francis & Gutiérrez, 2012; Francis & Strobach, 2013; for interesting exception in source memory see Francis, Strobach, Panelver, Martínez, Gurrola, & Solter, 2019), while comparisons between bilinguals and monolinguals sometimes do and at other times do not match predictions of the Frequency-Lag account.

To further consider why bilinguals did not out-perform monolinguals in Experiment 2, we tested 64 monolinguals in the same procedures as described in Experiment 1 and found equivalent recognition memory for English words (monolinguals, $d' = 1.34$; bilinguals, $d' = 1.25$), and not surprisingly (since they were effectively nonwords for this group) monolinguals exhibited poor memory for Spanish words (monolinguals, $d' = 1.17$; bilinguals, $d' = 1.62$)[4]. However, because bilinguals' memory for Spanish words was better than their memory for English words, when comparing bilinguals tested in Spanish, ($M = 1.62$, $SD = 0.44$), to

[4] The means for bilingual d' are different from those shown in Table 3 because it is d' for words in that language collapsed across list order and frequency.

monolinguals tested in English (*M* = 1.34, *SD* = 0.4), $t(122) = 2.34$, $p = 0.021$, (thereby testing each group in whatever language maximized their recognition memory performance), bilinguals exhibited better recognition memory. Thus, when maximizing the influence of Frequency-Lag, i.e., when testing bilinguals in their less frequently used language, a bilingual advantage in recognition memory emerged. Though it is highly speculative, this provides some support for the conclusion that bilingual advantages in recognition memory will be observed only when frequency-of-use lags sufficiently behind that of monolinguals.

Parallels can be found in the literature on language production and comprehension; within bilinguals frequency effects are consistently stronger in the nondominant than the dominant language, but bilinguals do not consistently exhibit larger frequency effects than monolinguals, and bilinguals are not always disadvantaged when tested in their dominant language relative to monolinguals (e.g., Duyck, et al., 2008; Ivanova & Costa, 2008; Gollan et al., 2011; Cop, et al., 2015). Importantly, we do not think the absence of a bilingual advantage in the present study reflects demographic differences between groups, rather potentially a result of bilinguals being highly proficient in English making it difficult to detect. Although bilinguals likely had lower socioeconomic status than monolinguals (see significant differences in parent education level; Table 1), this variable did not seem to affect recognition memory performance. Table 5 shows correlations between recognition memory performance and parent education level in Experiments 1 and 2; these tended to be small and not significant. Additional research is needed to identify which variables play a pivotal role in modulating the presence and/or absence of bilingual advantages in memory tasks.

[Table 5 near here]

Clinical Implications

The present study provides insights about factors that can affect verbal memory that have practical implications both for understanding how speakers of multiple languages might perform on standardized memory tests, and more generally for understanding what maximizes memory performance. Within participants, language dominance and frequency effects on recognition memory are found consistently and non-dominance and low-frequency seems to maximize recognition memory in bilinguals and monolinguals alike. Although bilinguals consistently perform recognition memory tasks better in their nondominant language, this does not imply that bilinguals should always be tested in their nondominant language to maximize performance. First, as reviewed above, testing in the nondominant language has the opposite effect on free recall, which is often of greater or at least of equal importance in clinical settings. Moreover, even in recognition memory, the nondominant language advantage was not found for each bilingual in the present study. While the majority of bilinguals tested in Experiment 1 recognized words better in Spanish than in English (n = 46; (collapsing across frequency levels), some bilinguals recognized words better in English than in Spanish (n = 17; only 6 of whom were tested in English-first, although all bilinguals in Experiment 1 had higher English than Spanish proficiency according to their MINT scores; see Table 1). Thus, it is premature to draw conclusions about how to best assess recognition memory in bilinguals at this point, and the answer to this question might vary with assessment goals.

In addition, while it is critical to test bilinguals in both languages to obtain an objective measure of language proficiency, and to determine which language is dominant which may maximize sensitivity in differential diagnosis (e.g., Gollan et al., 2010; Bedore et al., 2012), it is important to recognize that language of testing order can have significant effects on performance in a variety of tasks, including tests that do not directly measure “language skills”. This presents a difficult problem for clinical neuropsychologists that lacks any immediately obvious solutions (perhaps ideally bilinguals would be tested for proficiency in both languages on one day, and then all other testing could be deferred to a different day on which testing would be done in whatever language maximizes diagnostic sensitivity). Additional research will be needed to identify if free recall is also affected by testing order, which other standardized neuropsychological tests might be affected by language of testing order, and how much delay between testing blocks is needed to prevent between-language interference.

Conclusions, Study-limitations, and Future Directions

This present study revealed that order of task presentation influences recognition memory in bilinguals, with trends in the same direction in monolinguals. While group differences and order effects appeared not to be a simple reflection of differences in frequency of use – the results were generally consistent with the Frequency-Lag framework, which seemed to provide a ready explanation for many of the observed patterns that could not easily be explained by assuming between-language interference (which obviously could not affect performance in monolinguals). Additional work is needed to understand how proficiency differences between groups might affect allocation of attention during study, might introduce other differences in approach that affect performance in both recognition and recall, and to better define the relationship between frequency of use and memory in bilinguals and monolinguals alike.

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Declaration of Interest Statement

There were no conflicts of interest between the authors in completing this research.

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Tables

Table 1. Language characteristics

	Experiment 1				*Experiment 2*							
	Bilinguals				Bilinguals				Monolinguals			
	English first (n = 31)		English second (n = 32)		High frequency first (n = 32)		High frequency second (n = 32)		High frequency first (n = 32)		High frequency second (n = 32)	
Characteristic	***M***	*SD*	***M***	*SD*	***M***	*SD*	***M***	*SD*	***M***	*SD*	***M***	*SD*
Age (years)	19.8	1.3	20.2	2.6	20.1	2.1	20.1	2.2	20.2	2.5	21	2.8
Age of acquisition of English (years)	3.2	2.6	2.8	2.5	2.6	2.5	3.4	2,6	0	0.2	0	0.2
Age of acquisition of Spanish (years)	0.4	0.7	0.5	1.2	0.3	0.7	0.5	1.1	-	-	-	-
English proficiency self-rated	6.7	0.5	6.6	0.7	6.7	0.6	6.6	0.7	7.0	0.1	7.0	0.1
Spanish proficiency self-rated	6.2	0.9	5.9	1.1	5.9	1.1	5.7	1.1	-	-	-	-
Percent English use currently	83.3	14.1	84.4	12.9	78.3	16.5	81.8	15.2	99.5	1.8	99.1	3.7
Percent English use during childhood	57.5	20.8	52.4	16.7	59.5	14	57.3	16.7	98.8	1.8	97.3	3.9
Switching frequency currently	4.1	1.4	3.8	1.5	4.0	1.7	3.8	1.5	-	-	-	-
Switching in childhood	3.9	1.6	3.3	1.4	3.6	1.5	4.0	1.3	-	-	-	-
Primary Caregiver Education (years)	9.7	4.5	11.0	5.4	10.5	3.6	11.8	3.1	15.6	2.6	15.5	2.9
Secondary Caregiver Education (years)	10.8	4.6	9.5	4.6	11.2	4.1	10.7	3.1	14.3***	2.1	16.1	2.9
English MINT score	60.5	3.4	61.1	3.3	60.2*	3.0	61.7	3.1	64.3	2.2	64.7	2.1
Spanish MINT score	47.4	7.3	46.2	8.9	44.1	8.1	44.4	10.4	-	-	-	-
Translation matching task (240pts max)	239.1	1.4	238.4	2.6	-	-	-	-	-	-	-	-

*** for $p<.01$ * for $p<.05$

Table 2. Word characteristics for stimuli used in each experiment split by frequency category. Frequency per million for words in English and Spanish were obtained from the SUBTLEX-US and SUBTLEX-ESP databases, respectively (Brysbaert et al., 2009; Cuetos et al., 2011). Although comparison of English and Spanish frequency values must be interpreted with caution; there were no significant differences between high-frequency words (p = 0.91) or medium-frequency (p = 0.11) in the two languages.

	Experiment 1				***Experiment 2***	
	English		*Spanish*		*English*	
	High	Medium	High	Medium	High	Low
Frequency *(per million)*	126.5 (164.4)	27.0 (35.2)	123.9 (189.4)	44.7 (116.2)	133.9 (166.0)	3.7 (5.8)

Table 3. Average hit rate, false alarm rate, and d' values for bilinguals by list order in all conditions in Experiment 1.

Language	**List Order**	**Frequency**	**Hit Rate**	**False Alarm Rate**	***d'***
English	English first	High	0.67	0.28	1.18
		Medium	0.70	0.18	1.66
	English second	High	0.61	0.31	0.89
		Medium	0.65	0.23	1.30†
Spanish	English first	High	0.74*	0.24	1.56*
		Medium	0.78*	0.13†	2.16**
	English second	High	0.66	0.25	1.23
		Medium	0.69	0.18	1.57

** for p<.01 * for p<.05 and † for p<.10. Significance values are for within language comparisons across list order.

Table 4. Average hit rate, false alarm rate, and d' values for bilinguals by list order in all conditions in Experiment 2.

Language	List Order	Frequency	Hit Rate	False Alarm Rate	*d'*
Bilingual	High frequency first	High	0.67	0.29	1.14
		Low	0.74	0.19	1.81
	High frequency second	High	0.62	0.26	1.15
		Low	0.67†	0.21	1.43†
Monolingual	High frequency first	High	0.67	0.25	1.26
		Low	0.72	0.18	1.77
	High frequency second	High	0.69	0.28	1.28
		Low	0.70	0.18	1.56

** for $p<.01$ * for $p<.05$ and † for $p<.10$. Significance values are for between subject group comparisons.

Table 5. Bivariate correlations between primary/secondary parent education level and language proficiency and measures of recognition memory performance Experiments 1 and 2.

		Experiment 1					
		d'		*Hit Rate*		*False Alarm Rate*	
		Pearson's R	*p-value*	Pearson's R	*p-value*	Pearson's R	*p-value*
Bilinguals	Primary SES	0.13	0.30	0.14	0.29	0.002	0.98
	Secondary SES	0.09	0.44	0.12	0.35	0.02	0.88
	English MINT	-0.02	0.90	0.08	0.52	0.10	0.42
	Spanish MINT	0.18	0.16	0.14	0.26	-0.14	0.28

		Experiment 2					
		d'		*Hit Rate*		*False Alarm Rate*	
		Pearson's R	*p-value*	Pearson's R	*p-value*	Pearson's R	*p-value*
Bilinguals	Primary SES	-0.12	0.34	0.11	0.40	0.23	0.07
	Secondary SES	0.13	0.31	0.12	0.35	-0.03	0.82
	English MINT	0.01	0.97	-0.15	0.24	-0.07	0.57
	Spanish MINT	0.01	0.95	0.09	0.48	0.10	0.46
Monolinguals	Primary SES	0.06	0.61	0.13	0.31	0.19	0.14
	Secondary SES	-0.07	0.58	0.08	0.53	0.13	0.32
	English MINT	0.11	0.40	0.26	0.03*	0.09	0.50

** for *p*<.01 * for *p*<.05 and † for *p*<.10. Primary and Secondary SES refer to participant-reported parent education level.

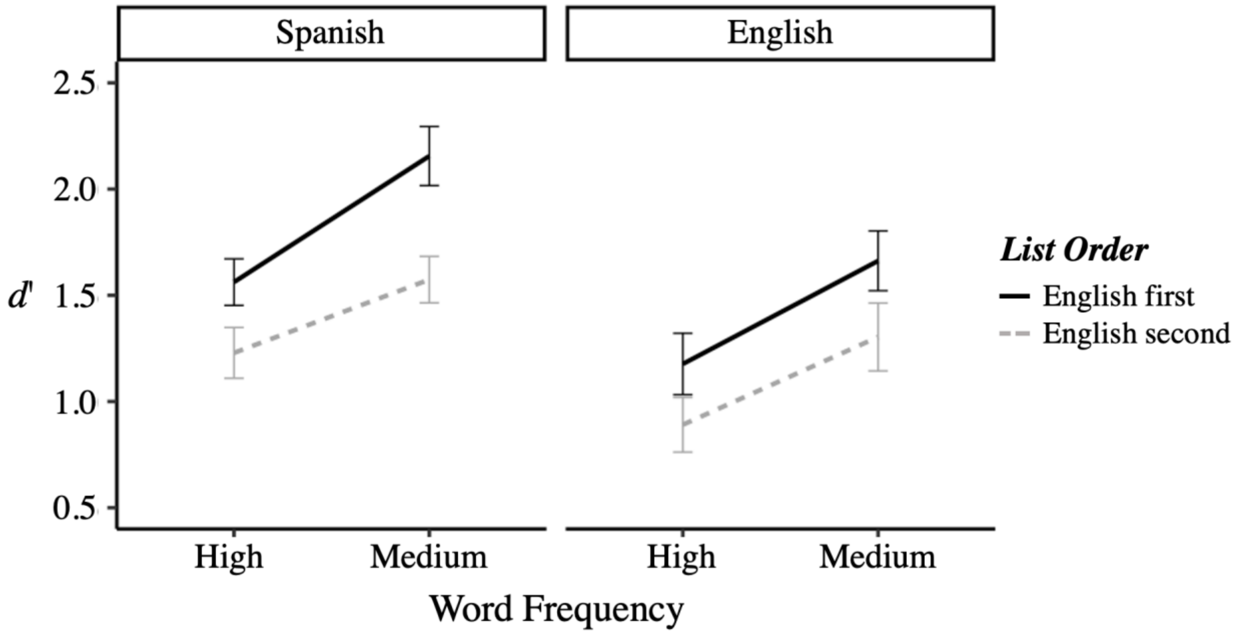

Figure 1. Bilingual recognition memory by word frequency (High/Medium), language (English/Spanish), and language of testing order (English first – Spanish second; Spanish first – English second) in Experiment 1.

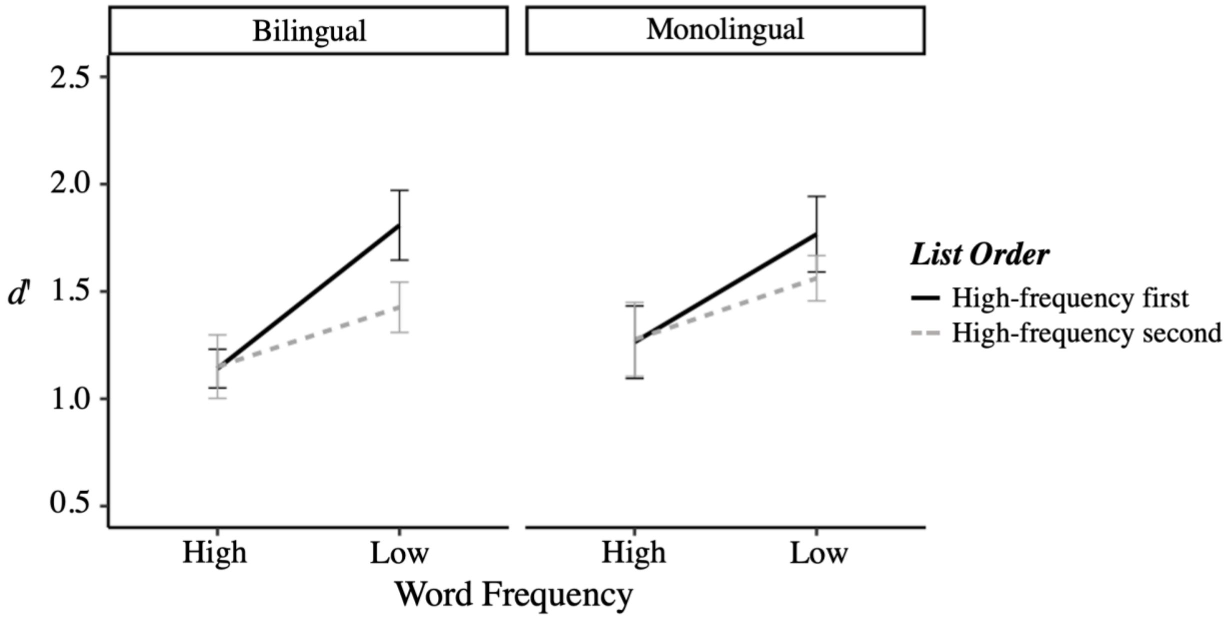

Figure 2. Recognition memory for words by word frequency (High/Medium), participant group (Bilingual/Monolingual), and list order (High-frequency first, Low-frequency second/ Low-frequency first – High-frequency second) in Experiment 2.

Appendix A

English and Spanish stimuli used in Experiment 1.

Experiment 1							
High Frequency				*Medium Frequency*			
English	**Spanish**	**English**	**Spanish**	**English**	**Spanish**	**English**	**Spanish**
advice	consejo	newspaper	periódico	achieved	logrado	ladies	señoras
alive	vivo	night	noche	aliens	marcianos	laid	puesto
alone	solo	noise	ruido	angry	enojado	lawyers	abogados
answer	respuesta	owner	dueño	arrow	flecha	leather	piel
apple	manzana	pain	dolor	baker	panadero	loading	cargando
beer	cerveza	party	fiesta	barely	apenas	loud	ruidoso
belief	creencia	path	camino	batch	tanda	meal	comida
bell	campana	plain	sencillo	bidding	ofertas	meat	carne
bird	pájaro	play	jugar	blind	ciego	mess	tiradero
block	cuadra	pool	alberca	bones	huesos	mud	lodo
blue	azul	pull	jalar	boss	jefe	nearby	cerca
border	frontera	queen	reina	breaks	romper	notebook	cuaderno
brand	marca	quote	citar	broad	amplio	pocket	bolsillo
chain	cadena	rain	lluvia	buildings	edificios	poll	encuesta
chair	silla	rock	piedra	buried	enterrado	pregnancy	embarazo
church	iglesia	room	cuarto	cage	jaula	pride	orgullo
clock	reloj	safety	seguridad	carpet	tapete	profits	beneficios
cold	frío	screen	pantalla	cheese	queso	pulling	jalando
couple	pareja	sell	vender	chess	ajedrez	rainbow	arcoíris
dance	baile	shadow	sombra	clay	barro	raw	crudo
deep	profundo	shape	forma	clothes	ropa	reed	caña
drink	bebida	ship	enviar	cloud	nube	rider	jinete
drive	manejar	shop	tienda	coin	moneda	rings	anillos
dust	polvo	shot	disparo	complain	quejarse	roots	raíces
easy	fácil	sister	hermana	cricket	grillo	rubber	hule
fair	justo	smart	inteligente	cry	llorar	sailor	marinero
falls	caídas	songs	canciones	curse	maldición	scream	gritar
fast	rápido	soul	alma	darkness	oscuridad	sells	vende
fear	miedo	speech	discurso	deaf	sordo	shirt	playera
field	campo	speed	velocidad	decline	disminuir	shower	ducha
fight	lucha	spent	gastado	demands	exigir	smell	olor
finger	dedo	square	cuadro	dress	vestido	snail	caracol
forest	bosque	stick	palo	drinking	tomando	socket	enchufe
forget	olvidar	stone	piedra	ears	orejas	sole	único
friends	amigos	street	calle	envelope	sobre	spelling	ortografía
games	juegos	strength	fuerza	estate	hacienda	spider	araña

glass	vaso		subject	tema		excited	emocionado		stages	etapas
hair	pelo		summer	verano		faces	caras		stone	piedra
hard	difícil		sword	espada		fails	fracasos		street	calle
head	cabeza		tape	cinta		fifth	quinto		tail	cola
health	salud		teacher	maestra		fishing	pescar		tales	cuentos
heart	corazón		team	equipo		fist	puño		tasks	tareas
heaven	cielo		test	prueba		fool	tonto		tears	lágrimas
horse	caballo		thinking	pensando		fork	tenedor		teeth	dientes
house	casa		thread	hilo		frozen	congelado		thrown	aventado
kind	tipo		together	juntos		garbage	basura		turkey	pavo
king	rey		tongue	lengua		gift	regalo		twisted	retorcido
land	tierra		travel	viajar		glasses	lentes		useless	inútil
leaves	hojas		trial	juicio		grabbed	agarró		versus	contra
lies	mentiras		trouble	dificultad		greetings	saludos		village	pueblo
lost	perdido		trust	confianza		grew	creció		wash	lavar
love	amor		waiting	esperando		hammer	martillo		wheels	llantas
magazine	revista		water	agua		helmet	casco		wings	alas
match	cerillo		weapon	arma		honey	miel		wise	sabio
meeting	junta		weather	clima		horn	cuerno		wishes	deseos
money	dinero		window	ventana		hunting	caza		witch	bruja
mouse	ratón		winter	invierno		ill	enfermo		witness	testigo
mouth	boca		women	mujeres		jacket	chamarra		wizard	mago
movie	película		write	escribir		jail	cárcel		world	mundo
murder	asesinato		yellow	amarillo		joined	unido		yeast	levadura

Appendix B

Stimuli used in Experiment 2.

Experiment 2						
High Frequency				*Low Frequency*		
advice	health	shape		absurd	grudge	pier
alive	heart	ship		abyss	hammer	pliable
alone	heaven	shop		acne	helmet	plush
answer	horse	shot		alchemy	heyday	quibble
apple	house	sister		arrow	hinder	quirk
belief	kind	smart		aunt	hull	rainbow
bell	king	song		bake	hunch	rattle
bird	land	soul		beagle	hurry	regal
blue	leaves	speech		bend	ignite	repent
border	lies	speed		birch	invasion	roach
brand	lost	spent		brag	invite	rubble
brown	love	square		broth	jewelry	scab
chain	magazine	stick		burp	knead	scoring
chair	match	stone		butter	leapt	seep
church	meeting	street		callous	lizard	sheer
clock	money	strength		cameo	locket	skew
cold	mouse	summer		clockwork	mauve	spasm
couple	mouth	sword		cloud	meal	spider
dance	movie	tape		cradle	meteor	spite
deep	murder	teacher		cricket	midwife	steam
drink	newspaper	team		crucial	mermaid	steamer
drive	night	test		deaf	mince	suede
dust	noise	thinking		dime	molar	supper
easy	owner	thread		dispute	mole	swing
fair	pain	together		distant	moth	talon
fall	party	tongue		dock	noodle	tart
fast	path	town		dose	nook	tattoo
fear	plain	travel		envy	nuance	toxin
field	play	trouble		evaluate	numb	turf
fight	pool	trust		facet	nurse	uphold
finger	pull	waiting		fiber	oblique	veneer
forest	queen	water		foal	obtuse	visor
forget	quote	weapon		folly	omen	wand
friend	rain	weather		foyer	orbit	wart
game	rock	window		genuine	orchid	weld
gate	room	winter		germ	ordeal	wishing
glass	safety	wire		gist	padlock	wool
hair	screen	women		gloss	pail	wring
hard	sell	write		godly	paste	yawn
head	shadow	yellow		grime	perjury	zoology