Published in final edited form as:

Memory. 2012 ; 20(4): 358–373. doi:10.1080/09658211.2012.667109.

Repetition priming within and between languages in verb generation: Evidence for shared verb concepts.

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Abstract

Although translation equivalents for concrete nouns are known to have shared core conceptual representations in bilingual memory (Francis, 1999), the status of translation-equivalent verbs has not been systematically tested. Three repetition-priming experiments using a verb generation task were used to determine whether verbs have shared representations across languages and identify the processes facilitated in repeated verb generation. In Experiment 1, fluent Spanish-English bilinguals exhibited repetition priming both within and between languages, but between-language priming was weaker. In Experiment 2, performance of nonbilingual English and Spanish speakers was equivalent to that of bilinguals responding in their dominant language. Experiment 3 used manipulations meant to isolate noun comprehension, verb concept selection, and verb production. The between-language priming in Experiments 1 and 3 indicates that verb concepts are shared across languages and that verb concept selection exhibits facilitation. Experiment 3 showed that the greater within-language priming was due primarily to facilitation of verb production processes.

Keywords

bilingualism; repetition priming; implicit memory; verb generation; conceptual representation

The representation of translation equivalents in bilingual memory has interested cognitive language and memory researchers because of the fundamental question of redundancy versus efficiency in representation. The weight of the evidence supports the conclusion that translation equivalents have shared core conceptual representations in both episodic and semantic memory (see Francis, 1999, 2005 for extensive reviews on this topic). However, cognitive experiments that provided direct evidence on this issue used primarily noun concepts as stimuli. The present study examines whether translation equivalent verbs have shared or separate core conceptual representations.

One of the strongest sources of evidence for shared conceptual representation comes from studies of repetition priming that transfers across languages. A handful of studies have shown conceptual repetition priming across languages using category exemplar generation priming (Francis, Fernandez, & Bjork, 2010), semantic classification priming (Francis & Goldmann, 2011; Zeelenberg & Pecher, 2003), and verb generation priming (Seger et al., 1999). Word fragment completion also exhibited priming across languages when the encoding task was meant to produce a very high level of semantic processing (Smith, 1991). With repetition of syntactic form, priming across languages was enhanced when the head verb of the prime and target phrases were translation equivalents (Schoonbaert, Hartsuiker, & Pickering, 2007). Most of these studies used nouns as stimuli, but the verb generation and syntactic priming studies provide some evidence that translation-equivalent verbs have shared conceptual representations. The present study examines this issue more directly.

Why Should Verbs Be Different?

Single-language studies of verb and noun representation suggest that there are important cognitive differences between nouns and verbs based on (1) neuropsychological and neuroimaging evidence suggesting neural specialization for nouns and verbs (for a recent review, see Vigliocco, Vinson, Druks, Barber, & Cappa, 2011); (2) developmental differences, including later age of acquisition for verbs (e.g., Gentner & Boroditsky, 2008); and (3) degree of relational processing involved (e.g., Black and Chiat, 2003). More importantly, two bilingual studies suggest that the relationship between translation equivalents differs for nouns and verbs. First, a study of text translation showed that after independent translation and back-translation, the original verbs were less likely to be preserved than the original nouns (Gentner, 1981). Second, when words were presented on two occasions for free associate generation, responses were slower and less consistent for verbs than for nouns in both within- and between-language conditions (van Hell & de Groot, 1998). These two findings give reason to suspect that core concepts for translation-equivalent verbs differ.

Repetition Priming Processes in Verb Generation: Evidence from Single-Language Studies

In a verb generation task, participants are shown a noun (e.g., airplane) and instructed to generate a verb (e.g., fly) that is associated with the noun. A simplified account of the cognitive processes involved is illustrated in Figure 1a, in which the task is divided into three steps, or sets of processes. The participant must first perceive and comprehend the noun, accessing or activating its concept. Second, an appropriate verb concept must be selected and activated; this process involves the noun-verb association. Third, the phonology of the verb must be accessed and produced aloud. We will refer to these processes as *noun comprehension*, *verb-concept selection*, and *verb production*, respectively. Any of these stages is a potential locus of facilitation when it is repeated, and this facilitation is measured as a reduction in RT for repeated relative to new items. Evidence that this facilitation is based on implicit rather than explicit memory processes comes from the finding that

amnesic patients show the same degree of facilitation as matched controls (Seger, Rabin, Zarella, & Gabrieli, 1997).

A few key studies shed light on the contributions of the three component processes. Comprehension of the noun does not appear to be a major factor in verb-generation priming. When a noun was repeated but elicited a different verb response from study to test, no facilitation was observed relative to new items (Seger et al., 1999). However, it is possible that speeded noun processing was offset by interference in production of a verb response inconsistent with the one produced at encoding. In a paradigm less likely to induce interference, when the generation task for a noun switched between verb generation and color generation (i.e., generating a color that is associated with a noun cue), a small but substantial facilitation effect for repeated nouns was observed (Thompson-Schill & Kan, 2001).

Production of the verb is a major factor in verb generation priming, as evidenced by the robust facilitation observed when the verb is repeated for different nouns (Prull, 2004; Seger et al., 1999); in these studies, neither noun comprehension nor verb-concept selection is repeated. The contribution of verb production to facilitation is in speeded retrieval of the phonology rather than articulation per se; facilitation following overt and covert verb generation did not differ substantially (Seger et al., 1999, Experiment 3).

The contribution of verb-concept selection processes involves the noun-verb relationship. There is mixed evidence for facilitation based on the noun-verb relationship. The finding of greater priming when the noun was repeated in one study (Prull, 2004) was not seen in other studies (Seger et al., 1997; Seger et al., 1999). Although such a result would suggest a role for verb concept selection, it would not be conclusive, because the effect could be based on noun comprehension. Thus, it is not clear whether having the identical noun-verb combination elicits stronger priming based on verb-concept selection, because it is difficult to isolate experimentally the process of verb concept selection from the process of noun comprehension.

Bilingual Verb Generation

Additional insight into this issue and the issue of shared concept representation can be gained through an examination of effects in bilingual verb generation. Given the strong evidence for shared core concept representation for translation equivalent nouns, two models can be derived to explain what processes are shared or distinct in verb generation in a bilingual's two languages (see Figure 1b). These models differ primarily in whether translation-equivalent verbs have shared or separate conceptual representations. The first model assumes that verbs in different languages have a shared concept. In this case, generating translation-equivalent verbs to translation-equivalent nouns in the two languages requires the process of accessing the same verb concept from the same noun concept. The second model assumes that in different languages, verbs have separate concepts. In this case, a verb generated in response to a specific noun in one language has no processes in common with the generation of the translation-equivalent verb to the translation-equivalent noun in

the other language. As these models illustrate, the process of verb concept selection is only shared across languages if both the noun and verb concepts are shared across languages.

Predictions of priming under these two models were derived based on transfer-appropriate processing logic (Morris, Bransford, & Franks, 1979; Roediger & Blaxton, 1987), assuming that repetition priming reflects repetition of cognitive processes from encoding to test. Thus, between-language repetition priming would be expected only under the shared verb-concept model. Under this model, between-language priming would reflect repetition of the process of selecting a verb concept based on the noun concept and provide the strongest evidence that verb concept selection contributes to priming in verb generation. Under either model, within-language repetition priming is expected based on comprehension of the noun, selection of the verb, and production of the verb. Therefore, within-language priming is expected to be stronger than between-language priming, to the extent that noun comprehension and verb production processes make a priming contribution.

Some preliminary evidence for between-language priming in verb generation was obtained in a previous study. Seger et al. (1999) conducted a bilingual experiment in which 12 Spanish-English bilinguals completed three “encoding” blocks of verb generation trials in English (with all noun cues repeated) and a fourth “test” block of verb generation trials in Spanish, with half repeated and half new noun cues. Significant priming was obtained for repeated relative to novel verbs. (Performance for repeated vs. novel nouns was not compared.) A comparison group of 12 monolingual English speakers performed the same protocol except that the final block was in English. The size of the priming effect did not differ significantly across groups. The authors concluded therefore, that (a) priming transferred completely across languages; (b) the results supported the “conceptual nature” of verb-generation priming, and (c) the locus of priming was in verb production. No conclusions were made about bilingual processing or representation.

Both the results and conclusions of the Seger et al. (1999) study are difficult to accommodate in the models we described above; such a result in isolation would suggest that verb-concept selection was the sole basis of facilitation in verb generation (within and between languages). It would be difficult to reconcile such a conclusion with the evidence that verb production processes also contribute. In fact, for several reasons, the results of that study cannot be considered definitive. First, with only 12 participants per group, power to find a medium sized effect was less than .25. Second, the within-language and between-language conditions were performed by populations with different language backgrounds, which is problematic, because the bilingual group had longer verb-generation RTs. Third, the response language in the final block of trials was different for the same-language and different-language groups.

In our study, we made several improvements to make a more definitive test of the degree of priming between-languages relative to within-languages. First, in Experiments 1 and 3, a within-subjects design was used, in which bilingual participants were exposed to both within- and between-language combinations. Second, the sample size was increased, thus increasing the power to detect a medium-sized effect to 99%. Third, the assignment of items to repeated and new conditions was controlled and not self-selected based on the response.

Experiment 1 measured repetition priming in verb generation within and between languages in bilinguals. Experiment 2 measured repetition priming within languages in non-bilingual English and Spanish speakers using the same materials. Experiment 3 used bilingual manipulations meant to selectively influence different stages of verb generation, in order to assess the contribution of each stage to the priming effect as well as replicate the effects of within- and between-language priming observed in Experiment 1. In all three experiments, noun-verb pairs were selected from a set of norms, and all critical manipulations were made within subjects. Although verb generation has typically been carried out with several blocks of trials, we followed a standard repetition priming protocol, making it comparable to other repetition priming procedures, such as picture naming and lexical decision.

Experiment 1

Experiment 1 examined verb-generation repetition priming within and between languages in a large sample of highly proficient Spanish-English bilinguals using all four possible language combinations. This experiment had as its first goal replication of the between-language priming effect previously observed with a small sample; between-language priming would be taken as evidence for shared core concept representation for translation-equivalent verbs. The second goal was to determine how between-language priming would compare to within-language priming in a bilingual sample. The degree of between-language priming relative to new-item controls would indicate the contribution of verb-concept selection in priming, whereas a shortfall relative to within-language priming would indicate the contribution of other processes, such as noun comprehension or verb production.

Methods

Participants.—The research participants were 84 self-identified Spanish-English bilinguals (53 women, 31 men) recruited primarily from introductory psychology classes at the University of Texas at El Paso. The University of Texas at El Paso is located within walking distance of the U.S.-Mexico border. It is a bilingual environment within a bi-national community of El Paso, TX and Ciudad Juárez, Chihuahua with a combined population of about 2 million people. Therefore, university students are exposed to both English and Spanish on a daily basis and have ample opportunity for interactions in both languages.

Most of the participants (92%) reported having learned Spanish before they started learning English; 4% had learned English before Spanish; and 5% had learned both languages simultaneously. The mean age at which participants reported beginning to learn the second language was 6 years old, and the modal age was 5, corresponding to the age that children start kindergarten in the United States. Given that the mean age was 20 years, they had on average 14 years of experience with their second language, and continued exposure to the first language. According to self-ratings of relative proficiency, 61% were classified as English dominant, and 39% were classified as Spanish dominant. On average, they reported that over the preceding month they had used English 46% of the time, Spanish 37% of the time, and a mixture of the two languages 17% of the time. All participants in this study were highly proficient speakers of Spanish and English who used both languages regularly. In

response to questions about ethnicity and nationality, 88% of participants self identified as Mexican-Americans and 12% as Mexican nationals. Fourteen additional participants completed the protocol but were excluded for failure to follow instructions or low accuracy (less than 50%) in the nondominant language.

Apparatus.—Stimuli were presented on a Macintosh G4 computer using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Vocal responses were timed using a PsyScope button box (New Micros, Dallas, TX) with a high-impedance microphone attached.

Design.—The experiments had a 3 (encoding condition) x 2 (test language) within-subjects factorial design. The encoding conditions were verb generation in English, verb generation in Spanish, and not presented. The languages of verb generation in the test phase were English and Spanish. The dependent variable was RT.

Stimuli.—The experimental stimuli were selected from a set of verb generation norms in English and Spanish that were collected from 320 participants for 225 nouns. In the norming study (de la Riva & Francis, 2005), verb responses to 225 nouns were collected from 80 English speakers, 80 Spanish speakers, and 160 bilinguals (randomly assigned to respond in English or Spanish). Participants were given the list of nouns and asked to write the first verb that came to mind that was associated with each noun. For each noun, the most common verb response was identified, and the proportion of times that verb was given as a response was computed separately in English and Spanish for bilinguals and nonbilinguals.

Seventy-two noun-verb pairs were needed to provide 12 stimuli per cell. From the larger set, we selected only nouns for which the most frequent verb responses in English and Spanish were translation equivalents. No two nouns were selected that had the same dominant verb response, and nouns that could have more than one meaning were avoided. Using these criteria, the dominant response was generated by at least 32% of the participants. The median Kuçera and Francis (1967) frequency of the selected English nouns was 28.50 per million, and the median frequency of the Spanish nouns was 38.30 per million (Sebastián Gallés, Martí Antonín, Carreiras Valiña, & Cuetos Vega, 2003). The mean letter length for the nouns was 5.4 in English and 6.3 in Spanish, and the mean letter lengths of the expected English and Spanish verb responses were 4.3 and 5.9, respectively. The mean agreement level was 61.2%.

The full set of 72 experimental noun-verb pairs was randomly divided into 6 sets of 12 noun-verb pairs. The level of agreement was matched across sets by randomly assigning the 6 items with the highest agreement, then the next 6, and so on, until the sets were completed. The assignment of the item sets to experimental conditions was also counterbalanced across participants using a Latin Square.

Procedure.—Participants were tested individually in sessions lasting approximately 30 min. The experiment was listed in an electronic sign-up system as being available to all students in introductory psychology courses. Upon arrival at the laboratory, potential

participants were screened by having them rate their relative proficiency in English and Spanish and then complete a more detailed language background questionnaire.

The primary task was verb generation, in which nouns appeared on the screen one at a time and participants generated aloud the first associated verb that came to mind. Each trial started with the presentation of a noun, which remained on the screen until a vocal response was recorded, and there was a 1250 ms delay before the next word appeared. Vocal RTs were recorded using a microphone/button box apparatus, and the experimenter noted all unexpected responses and timing errors, such as failure to activate the voice relay with the response or accidental activation of the voice relay before the response. Verbs were always generated in the same language as the noun stimulus.

The experiment consisted of an encoding phase and a test phase. At the beginning of each block of verb generation trials, instructions were given in the corresponding language. In the encoding phase, there was one block of English and one block of Spanish verb generation trials. Each block started with 3 filler items and continued with 24 experimental items in a random sequence. Between the encoding and test phases, participants had a break of about one minute during which instructions for the test phase were given. The test phase similarly had one block of English and one block of Spanish verb generation trials, with each block consisting of 36 experimental items presented in random sequence. Within each test phase block, one third of the items had been presented in English at encoding, one third had been presented in Spanish, and one third were new items that had not been previously presented. The order of languages was the same for the encoding and test phase, but this order was counterbalanced across participants.

Results

Analyses were conducted using both lenient and conservative inclusion criteria. In the lenient coding, all reasonable verb responses were included, so long as responses to a given noun were consistent from encoding to test. In the conservative coding, only the target responses (i.e., the most frequent responses given in the norming study) were considered valid. The patterns of means and significant and non-significant effects did not differ for the two analyses. We report only the analyses based on lenient coding, which utilized more of the data.

Data Processing.—Invalid trials were removed before calculating mean RTs for each participant. On average, 6.7% trials were excluded as response errors (i.e., non-verbs or “don’t know” responses), 4.9% of trials were removed due to machine timing errors, and 28.1% trials were removed as spoiled trials. Spoiled trials had correct test phase responses, but their primed status was compromised. Trials were considered spoiled if the encoding phase response was unacceptable (3.9%), acceptable but inconsistent with the test phase response (11.9%), or if the answer or its translation was given as a response to an earlier item (12.3%). The encoding phase responses corresponding to these spoiled items were also excluded. Items with RTs more than 2 standard deviations from the mean were removed as outliers, which resulted in the exclusion of 3.5% of the trials. Of the 72 test-phase trials, 56.8% were considered valid and 43.2% were considered invalid. This exclusion rate is

higher than in previous studies, because the trials that we consider to be spoiled (priming status compromised) were simply recoded in other studies from repeated to new or new to repeated based on the verb produced. Also, given that the mean agreement rate for the stimuli used was 61%, the proportion of spoiled trials in the present experiment is not surprising.

Encoding Phase Analysis.—Mean encoding phase RTs are given in Table 1. All inferential statistical tests were bi-directional with $\alpha = .05$. Statements about significance are based on the analysis by participants (F_1 , t_1), but analyses by items (F_2 , t_2) and $\min F$ are provided for reference. Overall, verb generation responses were 83 ms faster in English than in Spanish [$t_1(83) = 2.05$, $p = .044$; $t_2(71) = 1.94$, $p = .057$; $\min F(1, 154) = 1.98$, $p = .161$], likely because there were more English-dominant than Spanish-dominant bilinguals. English-dominant bilinguals responded faster in English ($M = 1414$, $SD = 331$) than in Spanish ($M = 1632$, $SD = 403$), and Spanish-dominant bilinguals responded faster in Spanish ($M = 1446$, $SD = 399$) than in English ($M = 1572$, $SD = 436$). Since language dominance is an important predictor of performance, English and Spanish responses were recoded for subsequent analysis to reflect the self-reported dominant and non-dominant languages. Overall, RTs were 183 ms faster in the dominant language than in the nondominant language [$t_1(83) = 5.04$, $p = .001$; $t_2(71) = 4.21$, $p = .001$; $\min F(1, 152) = 10.45$, $p = .002$].

Test Phase Analysis.—Test phase RTs are given in Table 2. As in the encoding phase, new-item RTs were faster (here 98 ms) in the dominant language than in the non-dominant language [$t_1(83) = 2.17$, $p = .033$; $t_2(71) = 2.90$, $p = .005$; $\min F(1, 136) = 3.01$, $p = .085$]. RTs were faster for repeated items than for new items for all of the four language combinations [for t_1 , $ps < .001$; for t_2 , $ps < .01$, for $\min F$, $ps < .03$]. Priming scores were obtained by subtracting repeated-item RTs from new-item RTs and are illustrated in Figure 2. The priming scores were submitted to a 2×2 repeated-measures ANOVA. Priming was stronger when the response language matched from encoding to test ($M = 306$, $SD = 242$) than when it changed ($M = 166$, $SD = 294$) [$F_1(1, 83) = 25.1$, $MSE = 65748$, $p < .001$; $F_2(1, 67) = 29.4$, $MSE = 72964$, $p < .001$; $\min F(1, 145) = 13.54$, $p < .001$]. However, final response language did not have an overall effect on the magnitude of the priming effects [$F_1 < 1$; $F_2 < 1$; $\min F < 1$], nor did it interact with the language match [$F_1(1, 83) = 1.798$, $MSE = 65087$, $p = .184$; $F_2 < 1$; $\min F < 1$].

Discussion

Overall, verb generation was faster in the dominant language, but neither within-language nor between-language repetition priming effects differed substantially for the dominant and non-dominant languages. Between-language priming was substantial, which replicates the bilingual portion of the Seger et al. (1999) results and supports the conclusion of shared verb-concept representation for translation-equivalent verbs. The between-language priming effect was substantially and significantly weaker than the within-language effect with about 54% the magnitude of the within-language effect. This pattern indicates that about half of the within-language effect is explained by facilitation of verb-concept selection processes, and the other half is explained by facilitation of other processes, such as noun comprehension or verb production.

The results of Experiment 1 contrast with the Seger et al. (1999) results in that priming between languages was attenuated relative to priming within a language. One possible reason for the discrepancy is differences across studies in the source of the within-language priming data. In Experiment 1, the same bilinguals who completed the between-language conditions contributed the within-language data. In the Seger et al. study, the within-language data were provided by English-speaking monolinguals. Because monolinguals had shorter verb-generation RTs in the control condition, it is reasonable to expect that they would exhibit smaller within-language priming effects than bilinguals, possibly even at a magnitude comparable to the bilingual between-language effect. Such a result would be consistent with both the repetition priming pattern observed in Experiment 1 and the pattern observed by Seger et al. (1999), and the data sets would no longer be contradictory. To evaluate this explanation, we conducted an experiment in which non-bilingual English speakers and Spanish speakers performed the procedures of Experiment 1 in their respective languages.

Experiment 2

Experiment 2 investigated verb-generation priming in a single-language context with participants who did not consider themselves to be bilingual. To make comparisons to the bilingual experiment more valid, half of the participants were English speakers (not fluent in Spanish or any other language) and half were Spanish speakers (not fluent in English or any other language). These groups were not expected to differ in terms of RT or repetition priming, but we allowed for that possibility by treating language group as a between-subjects factor. The primary purpose of this experiment was to explore any priming differences between bilinguals and non-bilinguals and to discover the reason for the apparent discrepancy with the Seger et al (1999) results. The non-bilinguals were expected to show faster RTs and smaller priming effects than the bilinguals.

Method

Participants.—Eighty-four new nonbilingual participants were recruited from the same sources as in Experiment 1. *English-speaking participants* were 42 English speakers (24 women, 18 men) who had low proficiency in Spanish or no knowledge of Spanish. The mean age was 20 years, and ethnicity was reported by 69% as Mexican-American, 14% as White non-Hispanic, 12% other ethnicities, and 5% did not report their ethnicity. *Spanish-speaking participants* were 42 Spanish speakers (33 women, 9 men) who had low proficiency in English. Most were enrolled in a section of introductory psychology that was taught in Spanish. The mean age was 20 years; 55% of participants identified as Mexican-Americans, 40% as Mexican nationals, and 5% did not report ethnicity. Two additional participants began the protocol but were excluded for failure to follow instructions.

Materials, Design, and Procedure.—Primed status (repeated vs. new) was manipulated within subjects. The 72 experimental stimuli were the same as those used in Experiment 1. This time, the items were divided into 3 sets of 24, with 2 sets repeated from encoding to test and 1 set serving as the new-item controls at test. This procedure maintained the ratio of repeated to new items used in Experiment 1. The assignment of sets to conditions was

counterbalanced across participants to control for specific-item effects. The procedure was the same as in Experiment 1 except that the session was conducted entirely in English for the English-speakers and entirely in Spanish for the Spanish-speakers. The encoding phase was completed in one block that began with 3 filler trials and continued with 48 experimental trials (with items from the 2 assigned sets randomly intermixed). At test, there was one block of 72 verb-generation trials, with the 48 repeated and 24 new items randomly intermixed. Brief rests were given halfway through the encoding sequence, between the encoding and test phase, and halfway through the test phase.

Results

Data Processing.—Mean RTs for correct responses were calculated based on the lenient coding criteria, and data were processed in the same manner as in Experiment 1. On average, 4.8% of trials were removed as response errors, 4.8% as machine timing errors, 26.4% as spoiled trials, and 4.0% as outliers. The proportion of valid trials was 59.9%, and 40.1% of trials were considered invalid. (The proportion of valid trials did not differ substantially from that of the bilinguals in Experiment 1 or 3.)

Response Times and Repetition Priming.—Encoding phase RTs (given in Table 1) did not differ substantially for the Spanish speakers and English speakers [$t_1 < 1$, $t_2 < 1$, $\min F < 1$]. Test phase RTs (given in Table 2) were analyzed using a 2 (language group) $\times$ 2 (primed status) mixed ANOVA. Repeated verbs were generated 287 ms faster than new verbs [$F_1(1, 82) = 131.12$, $MSE = 26482$, $p < .001$; $F_2(1, 71) = 203.36$, $MSE = 32324$, $p < .001$; $\min F(1, 141) = 79.72$, $p < .001$. English and Spanish RTs did not differ significantly [$F_1(1, 82) = 1.01$, $MSE = 279258$, $p = .318$; $F_2(1, 71) = 10.27$, $MSE = 46922$, $p = .002$; $\min F < 1$], and primed status did not interact with language [$F_1 < 1$, $F_2 < 1$, $\min F < 1$].

Comparisons with Bilingual Experiment.—Data from Experiments 1 and 2 were compared to identify possible group differences in RTs and repetition priming. Nonbilingual RTs were comparable to those of bilinguals generating verbs in their dominant language, [$t_1 < 1$; $t_2(166) = 1.14$, $p = .259$; $\min F < 1$], but less than those of bilinguals generating verbs in their nondominant language [$t_1(166) = 3.36$, $p = .001$; $t_2(71) = 5.96$, $p < .001$; $\min F(1, 118) = 8.58$, $p = .004$]. Priming effects for items repeated in the same language did not differ between nonbilinguals and bilinguals [$t_1 < 1$; $t_2 < 1$; $\min F < 1$], even when bilinguals responded in their non-dominant languages [$t_1 < 1$; $t_2 < 1$; $\min F < 1$]. The nonbilingual within-language priming effects were also substantially and reliably larger than the bilingual between-language priming effects [$t_1(166) = 2.99$, $p = .003$; $t_2(67) = 4.20$, $p < .001$; $\min F(1, 138) = 5.92$, $p = .016$]. These analyses were also conducted with priming expressed as a proportion of the control condition RT, and the pattern of effects did not change.

Discussion

Nonbilingual English and Spanish speakers showed repetition priming effects in verb generation, as expected. A comparison with Experiment 1 showed that nonbilingual RTs were faster than bilingual RTs, but within-language repetition priming effects were equivalent for nonbilinguals and bilinguals responding in their dominant language or even their non-dominant language. The nonbilingual within-language priming far exceeded the

level of bilingual between-language priming, refuting that potential explanation of the discrepancy between Experiment 1 and the Seger et al. (1999) study. Two other explanations of the discrepancy were also refuted. First, it could not be explained by differences in the number of verb-generation trials prior to test, because the within-language effects obtained in the two studies were comparable. Second, differences in how the control condition was defined (i.e., self-selected versus pre-determined) did not account for the discrepancy.

Another possible explanation was the obvious difference in sample sizes and therefore statistical power between the studies. To determine whether the means obtained in our study were truly inconsistent with the Seger et al (1999) data, 95% confidence intervals were created around the priming means given in that study, using the sample size of 12 for each interval. These confidence intervals were large enough to accommodate the patterns observed in Experiments 1 and 2, with weaker between-language than within-language priming. Although this explanation is not a particularly interesting or deep one, it appears to be the best candidate.

With this issue resolved, we return to the issue of the processes that contribute to priming in verb generation. Experiment 1 showed, with the between-language priming effects, that speeded verb-concept selection accounted for about half of the within-language effect. The attenuation of between-language priming relative to within-language priming indicates that about half of the within-language effect can be attributed to either noun comprehension or verb production, but it was not designed to estimate these influences separately. Experiment 3 was conducted to isolate each of the three sets of processes and obtain separate estimates of their priming contributions.

Experiment 3

Experiment 3 investigated the contributions of three potential bases of repetition priming in verb generation: *noun comprehension*, *verb-concept selection* and *verb production*. In Experiment 3, the final verb-generation test was always performed in English to allow for several encoding conditions to be tested within subjects given the limited number of noun-verb pairs that met the criteria for inclusion. Given that no differences in priming between languages were observed in Experiment 1, the inclusion of encoding conditions was a higher priority than having two test languages. Half of the participants were English dominant and half Spanish dominant; therefore half performed the test in their dominant language and half in their non-dominant language.

To estimate the contributions of the component processes of verb generation to repetition priming, we chose encoding tasks that were meant to prime each process selectively, thus isolating its contribution. To selectively prime noun comprehension, an English-Spanish noun-translation task was used at encoding. English-Spanish noun translation requires comprehension of the presented English noun and production of its Spanish translation-equivalent. Therefore, performing noun translation at encoding ought to produce priming in verb generation at test, based on repetition of English noun comprehension processes. To selectively prime verb-concept selection, a Spanish verb-generation task was used at encoding. As explained in the introduction, when verb generation is repeated in a different

language, only verb-concept selection processes are repeated. As demonstrated in Experiment 1, performing verb generation in Spanish at encoding produces priming in English verb generation at test, and that effect is expected to replicate. To selectively prime verb production, a Spanish-English verb-translation task was used at encoding. Spanish-English verb translation requires comprehending the presented Spanish verb and production of its English translation equivalent. Therefore, performing verb translation at encoding ought to produce priming in verb generation at test, based on repetition of English verb production processes. In order to estimate the combined influences of these repeated processes on repetition priming and provide a comparison condition, an identical English verb-generation task was used at encoding. Identical repetition of English verb generation produces priming that could be based on repetition of noun comprehension, verb-concept selection, and verb production processes.

Method

Participants.—The research participants were 72 self-identified Spanish-English bilinguals (48 women, 24 men) recruited from the same population as in Experiment 1, who received credit toward a course research requirement. (None had participated in Experiments 1 or 2.) Most of the participants (86%) reported having learned Spanish before they started learning English; 4% had learned English before Spanish; and 10% had learned both languages simultaneously. The mean age was 19 years. According to self-ratings of relative proficiency, half of the participants were classified as English dominant and the other half as Spanish dominant. On average, they reported that over the preceding month they had used English 47% of the time, Spanish 44% of the time, and a mixture of the two languages 9% of the time. All participants in this study were highly proficient speakers of Spanish and English who used both languages regularly. In response to questions about ethnicity and nationality, 82% of participants self identified as Mexican-Americans and 18% as Mexican nationals. Twenty-one additional participants completed the protocol but were excluded for failure to follow instructions or low accuracy (less than 50%) in the non-dominant language.

Design, Materials, and Procedure.—The design was a one-way within-subjects design with five encoding conditions: verb generation in English, verb generation in Spanish, noun translation from English to Spanish, verb translation from Spanish to English, and new items. The materials were identical to those of Experiment 1, with the exception of two items that were changed. The 6 sets of 12 experimental items were rotated through the encoding conditions across participants using a Latin square to control for specific-item effects.

The encoding phase had 4 blocks of trials, verb generation in English, verb generation in Spanish, noun translation from English to Spanish, and verb translation from Spanish to English. The order of these blocks was counterbalanced across participants using a balanced Latin square to control for order effects. Each block consisted of 3 practice trials and 12 trials with critical items. Between the encoding and test phases, participants took a short break. In the test phase, the 4 sets of items presented at encoding and the remaining 2 sets were randomly intermixed and presented in English for English verb generation.

Results

Data Processing.—Mean RTs for correct responses were calculated based on the lenient coding criteria, and data were processed in the same manner as in Experiments 1 and 2. On average, 6.4% of trials were excluded as response errors, 5.5% as machine timing errors, 23.8% as spoiled trials, and 4.7% as outliers. The proportion of valid trials was 59.6%, and 40.4% of trials were considered invalid.

Encoding Phase Analysis.—Mean RTs for verb generation in the encoding phase are given in Table 1. Participants performed verb generation in both languages, and RTs were reliably faster in the dominant language than in the non-dominant language [$F_1(1, 70) = 6.51$, $MSE = 128342$, $p = .013$; $F_2 < 1$; $\min F < 1$]. In English-Spanish noun translation, there was no reliable RT difference between English-dominant ($M = 1168$, $SD = 305$) and Spanish-dominant participants ($M = 1138$, $SD = 239$) [$t_1(70) < 1$; $t_2(49) = 2.697$, $p = .010$; $\min F < 1$]. In Spanish-English verb translation, English-dominant participants ($M = 1156$, $SD = 223$) had faster RTs than Spanish-dominant participants ($M = 1318$, $SD = 302$), [$t_1(70) = 2.59$, $p = .01$; $t_2(49) = 2.061$, $p = .045$; $\min F(82) = 2.601$, $p = .111$]. Noun translation error rates ($M = 8.7\%$, $SD = 9.4\%$) and verb translation error rates ($M = 8.0\%$, $SD = 7.9\%$) were comparable.

Test Phase Analysis.—RTs for English verb generation in the test phase are given in Table 3. For new items, Spanish dominant participants had longer RTs than English dominant participants [$t_1(70) = 3.30$, $p = .002$; $t_2(49) = 3.45$, $p = .001$; $\min F(82) = 5.690$, $p = .019$]. Priming scores were obtained by subtracting repeated-item RTs from new-item RTs and are illustrated in Figure 3. Priming was significant in three of the encoding conditions, English verb generation (same language), Spanish verb generation (different language), and verb translation [for t_1 , $ps < .001$; for t_2 , $ps < .005$; for $\min F$, $ps < .02$]. However, priming for the noun translation condition was not significant [$t_1(71) = 1.24$, $p = .218$; $t_2 < 1$; $\min F < 1$].

Priming scores were submitted to a 4 (encoding condition) $\times$ 2 (language dominance) mixed ANOVA. Priming scores differed across encoding conditions [$F_1(3, 210) = 16.35$, $MSE = 95141$, $p < .001$; $F_2(3, 147) = 9.51$, $MSE = 227953$, $p < .001$; $\min F(3, 263) = 6.014$, $p = .015$]. Paired comparisons were made among the different encoding conditions. Specifically, identical verb generation produced more priming than any of the other conditions [for t_1 , $ps < .001$; for t_2 , $ps < .005$; for $\min F$, $ps < .02$]. Priming in different-language verb generation and verb translation conditions did not differ reliably [$t_1(71) = 1.25$, $p = .217$; $t_2 < 1$; $\min F < 1$]. However, verb translation produced more priming than noun translation [for t_1 , $p = .002$; for t_2 , $p < .001$; for $\min F$, $p = .017$], and priming in different-language verb generation was significantly higher than in noun translation [for t_1 , $p = .039$; for t_2 , $p = .007$; for $\min F$, $p = .097$]. There was no main effect of language dominance on priming scores, nor did it interact with encoding condition [$F_1s < 1$; $F_2s < 1$; $\min F's < 1$].

Discussion

As expected, the different-language verb generation, noun-translation, and verb-translation conditions each produced a smaller priming effect than identical repetition. Experiment 3

replicated the between-language repetition-priming effect seen in Experiment 1, providing further evidence that speeded verb-concept selection contributes to priming in verb generation. As in Experiment 1, this effect was attenuated relative to within-language priming, indicating that other processes also contribute to the within-language effect. Significant and substantial priming following verb translation indicates that speeded verb production contributes to priming in verb generation. The noun-translation task did not produce significant priming in verb generation, suggesting that the contribution of noun comprehension to priming in verb generation is negligible. Therefore, repetition priming in verb generation is based primarily on verb-concept selection and verb production.

General Discussion

Bilinguals exhibited repetition priming in verb generation, both within and between languages. In contrast to the Seger et al. (1999) study, the between-language priming in Experiments 1 and 3 was attenuated relative to within-language priming, about half the magnitude of the within-language effect. As explained with the models presented in the introduction, between-language priming would only be expected when both the noun and verb have shared conceptual representations across languages, because that is the only situation in which the verb selection process would be shared across languages. Therefore, the present between-language priming effects support shared conceptual representations for translation equivalents of both nouns and verbs, at least for highly proficient bilinguals. The results of two previous studies involving conceptual or syntactic priming (Schoonbaert et al., 2007; Seger et al., 1999) were also consistent with the shared verb-concept model. It is of course possible that the degree of overlap in core conceptual representations for translation-equivalent verbs differs for less proficient bilinguals. Also, it may well be the case that verbs exhibit stronger transfer across languages when, as in the present study, they are encountered in the context of particular nouns that constrain their meaning than when they are encountered in isolation.

Although previous findings of noun-verb differences, particularly in bilinguals, gave us reason to suspect that verb concepts might not be shared, the present results and conclusions in favor of the shared verb-concept model do not directly contradict those previous findings. Specifically, our conclusions are not inconsistent with the Gentner (1981) translation study, in which nouns were more likely than verbs to be preserved through translation and back-translation, or the van Hell & de Groot (1998) associate generation study, in which free associates were produced more slowly and less consistently to verbs than to nouns. First, in the Gentner (1981) study, the nouns and verbs to be translated were part of a pre-existing text passage, and therefore it does not appear that there was any attempt to match the nouns and verbs on lexical properties such as frequency, letter length, ambiguity of meaning within a language. Also, the translation and back-translation were only attempted by 7 pairs of participants on 2 passages containing a combined total of 35 common nouns and 35 verbs. Therefore, it is difficult to generalize these results. In the word association study, the discrepancy in association consistency for verbs relative to nouns is no greater when the language of association changes from the first to second time than when it stays the same (van Hell & de Groot, 1998).

The reduced facilitation for between-language relative to within-language repetition is consistent with a transfer-appropriate processing logic in which shared processes from encoding to test are the causal basis of facilitation. Whereas an identical repetition involves repetition of noun comprehension, verb concept selection and verb production, between-language repetitions only involve repetition of verb concept selection. With only a subset of processes repeated in the between language case, reduced priming was an expected finding. The reduced facilitation for between-language priming is superficially at odds with the results of Seger et al. (1999), and we explored reasons for the discrepancy. However, as explained in the Discussion of Experiment 2, the mean priming scores obtained in the present study do not fall outside confidence intervals for the means derived from the Seger et al. (1999) data. Indeed, the substantial variability in the response times for verb generation requires testing large samples, as obtained in the present study.

Although not a focus of the present study, it should be noted that we did not observe substantial L1-L2 differences in repetition priming. The present results may, in fact, underestimate the true effects of bilingual proficiency or language dominance on verb-generation response times and priming. First, because language dominance was classified using self-report measures rather than with objective assessments, some individuals may have been misclassified. Second, the bilingual participants were highly proficient in both languages and would be expected to show smaller proficiency effects than would less balanced bilinguals. Third, in making comparisons between bilinguals and monolinguals, it would be advisable in future studies to match groups on measures of cognitive ability. Finally, we recognize that the age of acquisition of the verbs may impact the nature of the conceptual representations formed, but further research would be needed to address this question.

Priming Processes in Verb Generation

Three component processes of verb generation were identified as potential bases of repetition priming: noun comprehension, verb-concept selection, and verb production. As explained in the introduction, no consensus had been reached on the contribution of verb-concept selection. Whereas Thompson-Schill and Kan (2001) claimed that the selection of specific semantic information, such as an associated verb, did contribute to priming, Seger et al. (1999) concluded that the noun-verb relationship (the basis of verb-concept selection) was inconsequential, and Prull (2004) cited a role for the noun without specifying whether it was the noun itself or the pairing with the verb that contributed to priming. Part of the difficulty in determining the role of verb-concept selection has been the difficulty of isolating component processes with single-language manipulations.

The present study isolated the noun-verb association (verb-concept selection) through the use of bilingual materials. The between-language effects in Experiments 1 and 3 indicate that repetition of *verb-concept selection* elicited priming in verb generation. Given that the magnitude of priming was greater within languages than between languages, it is also clear that other processes play a role in verb generation priming. Experiment 3 showed that verb production also makes a large contribution to priming. In contrast, the contribution of noun-comprehension is small to non-existent. Thus, most if not all of the advantage for an

identical within-language repetition over a between-language repetition is due to repetition of verb production processes.

Conclusions

Verb generation exhibited substantial and reliable repetition priming between languages, indicating that translation equivalents of both nouns and verbs have shared core conceptual representations in bilinguals. The between-language repetition conditions also allowed for isolation of the noun-verb concept selection process and demonstrated that verb generation priming is based in large part on the specific noun-verb pairing, or the process of selecting an appropriate verb concept for a particular noun concept. Nevertheless, repetition priming was greater within languages than between languages, indicating that other processes in verb generation were also facilitated. Manipulations that targeted facilitation of noun comprehension, verb-concept selection, and verb production processes separately showed that verb production also accounts for a substantial portion of the verb-generation priming effect.

Acknowledgments

Experiments 1 and 2 were completed as a master's thesis by the first author. This research was supported by National Institutes of Health grant MH61765 to the second author and research assistant funding from the University of Texas at El Paso's NSF ADVANCE grant. We thank Manuel Herrera, Irma Rodríguez, and Julissa Caraballo for assistance in the early stages of this project. The results of Experiments 1 and 2 were presented at the 5th International Symposium on Bilingualism (2005) and the 2005 Conference of the Western Psychological Association. The results of Experiment 3 were presented at ARMADILLO, the Southwest Cognition Conference.

Appendix A: Noun Stimuli, Expected Verb Responses, and Percent Agreement

English Noun	Verb Response	Spanish Noun	Verb Response	Agreement (%)
SCISSORS	CUT	TIJERAS	CORTAR	95.6
CHOIR	SING	CORO	CANTAR	90.0
NIGHTCLUB	DANCE	DISCOTECA	BAILAR	89.4
AIRPLANE	FLY	AVIÓN	VOLAR	86.9
CIGAR	SMOKE	CIGARRO	FUMAR	85.3
BOOK	READ	LIBRO	LEER	84.7
OXYGEN	BREATHE	OXÍGENO	RESPIRAR	84.4
PENCIL	WRITE	LÁPIZ	ESCRIBIR	83.1
CHAIR	SIT	SILLA	SENTAR	81.9
TOWEL	DRY	TOALLA	SECAR	79.7
POOL	SWIM	ALBERCA	NADAR	78.8
ASSASSIN	KILL	ASESINO	MATAR	78.8
GUM	CHEW	CHICLE	MASTICAR	77.8
JOKE	LAUGH	CHISTE	REIR	77.5
BEER	DRINK	CERVEZA	TOMAR	76.6
HANGER	HANG	GANCHO	COLGAR	76.3

English Noun	Verb Response	Spanish Noun	Verb Response	Agreement (%)
BRAIN	THINK	CEREBRO	PENSAR	74.7
ACTOR	ACT	ACTOR	ACTUAR	74.4
BED	SLEEP	CAMA	DORMIR	73.8
BANANA	EAT	PLÁTANO	COMER	73.1
PROFESSOR	TEACH	PROFESOR	ENSEÑAR	70.9
BABY	CRY	BEBÉ	LLORAR	70.6
DOLL	PLAY	MUÑECA	JUGAR	69.7
KEY	OPEN	LLAVE	ABRIR	69.7
PAN	COOK	SARTÉN	COCINAR	68.4
LIPS	KISS	LABIOS	BESAR	67.2
MOVIE	WATCH	PELÍCULA	VER	67.2
ATHLETE	RUN	ATLETA	CORRER	66.6
PRIZE	WIN	PREMIO	GANAR	66.3
BELL	RING	CAMPANA	SONAR	65.9
NUMBER	COUNT	NÚMERO	CONTAR	65.6
WIND	BLOW	VIENTO	SOPLAR	63.8
DOG	BARK	PERRO	LADRAR	63.1
STAIRS	CLIMB	ESCALERAS	SUBIR	62.5
MECHANIC	FIX	MECÁNICO	ARREGLAR	62.2
SIDEWALK	WALK	BANQUETA	CAMINAR	60.6
LANGUAGE	SPEAK	IDIOMA	HABLAR	60.0
RADIO	LISTEN	RADIO	ESCUCHAR	59.7
BEE	STING	ABEJA	PICAR	58.8
MARKET	SHOP	MERCADO	COMPRAR	57.8
BACKPACK	CARRY	MOCHILA	CARGAR	57.2
FIRE	BURN	FUEGO	QUEMAR	55.0
EYE ^a	SEE	OJO	VER	54.7
BURGLAR	STEAL	LADRÓN	ROBAR	54.4
SKUNK	SMELL	ZORRILLO	OLER	54.1
PROBLEM	SOLVE	PROBLEMA	RESOLVER	52.5
WHEEL	TURN	RUEDA	RODAR	52.2
CAR	DRIVE	COCHE	MANEJAR	51.6
GARBAGE	THROW	BASURA	TIRAR	50.3
GUN	SHOOT	PISTOLA	DISPARAR	50.0
SOAP	WASH	JABÓN	LAVAR	49.7
HORSE	RIDE	CABALLO	MONTAR	48.4
MERCHANT	SELL	COMERCIANTE	VENDER	47.8
ARCHITECT	BUILD	ARQUITECTO	CONSTRUIR	47.5
STUDENT	STUDY	ESTUDIANTE	ESTUDIAR	46.9
FINGER	POINT	DEDO	APUNTAR	46.6
MONEY	SPEND	DINERO	GASTAR	46.6
STAR	SHINE	ESTRELLA	BRILLAR	45.9

English Noun	Verb Response	Spanish Noun	Verb Response	Agreement (%)
BRIDGE	CROSS	PUENTE	CRUZAR	45.3
LION	ROAR	LEÓN	RUGIR	44.7
RELIGION	PRAY	RELIGIÓN	REZAR	44.1
GYM	EXERCISE	GIMNASIO	EJERCITAR	43.8
GIFT	GIVE	REGALO	DAR	43.8
SHIP	SAIL	BARCO	NAVEGAR	43.1
WAITER	SERVE	MESERO	SERVIR	42.8
HAIR	COMB	PELO	PEINAR	42.2
HEART	BEAT	CORAZÓN	LATIR	40.6
CLOTHING	WEAR	ROPA	VESTIR	40.3
VOLCANO	ERUPT	VOLCÁN	ERUPTAR	40.0
RABBIT	HOP	CONEJO	SALTAR	36.9
MIRROR ^a	LOOK	ESPEJO	MIRAR	35.9
KNEE	BEND	RODILLA	DOBLAR	32.8
WALL ^b	PAINT	PARED	PINTAR	31.3
CLOUD ^b	RAIN	NUBE	LLOVER	29.1

Note: Expected responses were the most common response in the norming study. Agreement represents the percentage of participants in the norming study who gave the expected verb response, averaged across languages and across monolinguals and bilinguals.

^a Items used in Experiments 1 and 2 but not Experiment 3

^b Items used in Experiment 3 but not in Experiments 1 and 2

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Figure 1.

Processes involved in verb generation under three models: (A) monolingual English model; (B) bilingual shared verb concept model; and (C) bilingual separate verb concept model.

Figure 2. Repetition priming in verb generation in Experiments 1 and 2 as a function of encoding language and final verb-generation language. Error bars indicate standard errors of the mean (based on the analysis by participants).

Figure 3.

Repetition priming in verb generation in Experiment 3 as a function of encoding task and final verb-generation language. Error bars indicate standard errors of the mean (based on the analysis by participants).

Table 1.

RT Means (SDs) for Verb Generation in the Encoding Phases of Experiments 1, 2, and 3

Experiment: Language Group	RT (ms)			
	English	Spanish	L1	L2
Experiment 1: Bilinguals (N = 84)	1476 (381)	1559 (406)	1426 (357)	1609 (415)
Experiment 2: English Speakers (N = 42)	1415 (315)	--	1415 (315)	--
Spanish Speakers (N = 42)	--	1408 (370)	1408 (370)	--
Experiment 3: Bilinguals (N = 72)	1669 (429)	1771 (536)	1644 (492)	1796 (471)

Table 2.

Test Phase RTs for Verb Generation in Experiments 1 and 2 as a Function of Encoding Condition and Test Language

Encoding Condition	Bilinguals (Expt. 1)			Nonbilinguals (Expt. 2)		
	L1	L2	Overall	English	Spanish	Overall
Not Presented	1572	1670	1621	1491	1549	1520
Identical Repetition	1286	1344	1315	1179	1285	1232
Different Language Repetition	1398	1522	1460	--	--	--

Table 3.

Test Phase RTs for Verb Generation as a Function of Encoding Condition in Experiment 3.

Encoding Condition	Verb Generation Language at Test		
	L1	L2	All (English)
Not Presented	1693	1990	1842
Identical Repetition	1295	1556	1426
Different-Language Repetition	1487	1853	1670
Noun Translation	1666	1886	1776
Verb Translation	1468	1739	1603