Repetition Priming in Picture Naming and Translation Depends on Shared Processes and Their Difficulty: Evidence From Spanish–English Bilinguals

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Two experiments with highly fluent Spanish–English bilinguals examined repetition priming of picture identification and word retrieval in picture naming. In Experiment 1, between-language priming of picture naming was symmetric, but within-language priming was stronger in the nondominant language. In Experiment 2, priming between picture naming and translation was symmetric within both the dominant language and the nondominant language, but priming was stronger in the nondominant language. A mathematical model required only 3 process parameters to explain the pattern of priming across 8 conditions. These results indicate that shared processes are the basis of priming, that difficulty influences priming only at the process level, and that translation in both directions is concept mediated in fluent bilinguals.

One of the most influential concepts in memory research is transfer appropriate processing, the idea that the degree of transfer from study to test depends on the degree to which cognitive processes overlap from study to test (Morris, Bransford, & Franks, 1977; Roediger & Blaxton, 1987). This principle, which was introduced as a complement to the encoding specificity principle (Tulving & Thomson, 1973), has been useful in predicting and explaining a number of memory and transfer phenomena in explicit and implicit memory. However, because transfer appropriate processing is a principle rather than an explicit model (Franks, Bilbrey, Lien, & McNamara, 2000), the manner in which it is interpreted and applied varies considerably across researchers in terms of what processes are considered and how hypotheses about transfer-appropriate effects are derived. One criticism of the transfer appropriate processing principle has been that it has not been specified sufficiently for it to be testable (Gorfein & Bubka, 1997).

Within the context of repetition priming, the present study tests the implications of an interpretation of transfer appropriate processing in which common processes between study and test tasks are assumed to be the causal basis of facilitation. Processes are defined in terms of the operations completed, rather than the levels of representation activated; practice of these processes is assumed to lead to a strengthening of the links or connectivity between representations, rather than increasing activation in the representations themselves. This approach to transfer appropriate processing is similar to those used by previous researchers to derive predictions about repetition priming in object recognition (Stankiewicz, Hummel, & Cooper, 1998) and in producing words based on the concept (Monsell, Matthews, & Miller, 1992; Sholl, San-karanarayanam, & Kroll, 1995). However, in the present study, we take this logic a few steps further by making the bases for deriving predictions more explicit, including what it means for a process to be shared across tasks. Assumptions about the types of processes that can elicit repetition priming or that can benefit from it are similar to those proposed by Franks et al. (2000). New implications of our approach are tested across two experiments. This version of transfer appropriate processing differs from other transfer appropriate processing explanations in the repetition priming literature. For example, other approaches have emphasized the match between data-driven and conceptually driven processing at study and test (Roediger & Blaxton, 1987; Weldon & Roediger, 1987), the match between domains of semantic representation accessed at study and test (Thompson-Schill & Gabrieli, 1999; Vriezen, Moscovitch, & Bellos, 1995), and the match between perceptual representation systems operating at study and test (Schacter, 1992; Tulving & Schacter, 1990). More generally, the present approach differs from those that define the match between study and test in terms of the representations activated, levels of representation for processing, type of processing, or the stimuli or cues present.

Across a variety of naming, generation, and classification tasks, the measure of priming is the reduction in response times for repeated items relative to new items. If practice of shared processes is assumed to be the primary basis of this facilitation, then it can be inferred that when there is more shared processing, there will be more facilitation of repeated items. Two implications can be derived from this inference. First, when the shared processes are more difficult, there ought to be more shared processing and therefore stronger priming. Second, across situations in which the same processes are shared or those in which the shared processes
are equally difficult, shared processing should be equivalent, leading to equivalent priming effects. Thus, process-based difficulty effects on priming can be derived naturally out of transfer appropriate processing logic. However, the question of whether difficulty does in fact influence priming at a process level or at the level of the entire task has not yet been determined empirically. Perhaps this is because within the context of repetition priming, the causal bases of difficulty effects have never been the focus of investigation.

In general, more difficult tasks, those with longer response latencies and higher error rates, benefit more from repetition, presumably because there is more room for improvement. For example, picture naming, which is more difficult than word naming and picture categorization, benefits more from repetition than do the latter two tasks (Durso & Johnson, 1979). Similarly, within a given task, more difficult or slower items tend to benefit more from repetition. For example, picture naming latencies are longer and priming effects stronger for pictures with low name agreement (Park & Gabrieli, 1995), with names that have low frequency in the language (Wheeldon & Monsell, 1992), and with names that are acquired at a later age (Barry, Hirsh, Johnston, & Williams, 2001). However, it is not clear whether these differences in priming arise because of overall task difficulty or because of more difficult processes being practiced at study and repeated at test.

Under conditions of identical repetition, the difficulty of the entire task and the difficulty of the shared processes are necessarily confounded, and it is therefore not possible to determine which is responsible for the observed difficulty effects on priming. To determine whether difficulty effects operate at a task or process level, there are two possible approaches. One is to hold a task constant while varying the difficulty of the processes to be primed, an approach that has been applied in the context of a separate study (Francis, 1998; Francis et al., 2002). The other is to hold a process constant while varying the difficulty of the task to be primed, which is the approach applied in the present investigation. In two experiments, we attempted to selectively prime processes that are both shared by and necessary for two different tasks.

As a strategy for manipulating task difficulty while holding a process constant, the experiments in the present study were constructed using bilingual materials. Bilingual materials allow for the assignment of two different labels (i.e., translation equivalents) to refer to a single concept or object, but these labels have distinct phonological and orthographic forms. This approach has the implicit assumption that in fluent bilinguals, pairs of translation equivalents are associated with the same underlying conceptual representation. The cognitive experimental literature on bilingual semantic and episodic memory and language processing shows definitively that for highly proficient bilinguals, translation equivalents of concrete nouns have shared conceptual representations (for reviews of the evidence, see De Groot, 1992; Francis, 1999, in press). This evidence for common semantic representation is sufficient to justify using bilingual translation equivalents as alternate paths to a single conceptual representation.

Comprehension and Production Processes in Picture Naming and Translation

Picture naming and translation both benefit substantially from repetition, exhibiting faster response times for repeated items than for new items. Since the initial demonstration of repetition priming in picture naming (Durso & Johnson, 1979), a number of studies have replicated the effect and explored its characteristics. Facilitation for repeated pictures is durable over delays of several weeks (Mitchell & Brown, 1988; Mitchell, Brown, & Murphy, 1990) and is preserved in global amnesia (Cave & Squire, 1992) and Alzheimer’s disease (Gabrieli et al., 1999). Translation, though much less explored, also exhibits repetition priming (Francis, Jameson, Augustini, & Chávez, 2000; Tokowicz & Kroll, 2001). In general, maximal priming occurs when the prime task and the test task performed on an item match exactly in terms of the stimulus format, the task instructions, and the response (Franks et al., 2000). However, substantial priming can also be elicited by prior experience with the items on similar tasks, including those that are thought to share sets of processes.

Each process necessary to perform a task such as picture naming or translation is a potential locus of priming when the task is repeated. The processes required for picture naming and translation have been delineated by previous research. Picture naming requires accessing the concept represented by the picture before retrieval and production of the name. Evidence that picture naming is concept mediated comes from monolingual studies showing that although picture naming takes much longer than word naming, picture categorization takes less time than word categorization (Durso & Johnson, 1979; Potter & Faulconer, 1975). In fluent bilinguals, picture naming is conceptually mediated in both the dominant and nondominant language (Chen & Leung, 1989; Kroll & Stewart, 1994; Potter, So, von Eckhardt, & Feldman, 1984; Sholl et al., 1995). Concept-mediated picture naming can be decomposed into two sets of processes: (a) picture identification, which includes perceptual processes and retrieval of the concept, and (b) word retrieval, which includes selection of the appropriate word and phonology as well as articulating the overt verbal response.

Translation also appears to require accessing the appropriate concept before retrieving and producing the corresponding word in the target language. Concept-mediated translation can be decomposed into two sets of processes: (a) word comprehension, which includes perceptual processes and retrieval of the concept, and (b) word retrieval in the target language. There is consensus in the literature that translation from the dominant to the nondominant language is concept mediated in fluent bilinguals (Chen & Leung, 1989; Kroll & Curley, 1988; Kroll & Stewart, 1994; Potter et al., 1984; Sholl et al., 1995). Some researchers have concluded that translation from the nondominant to the dominant language is also concept mediated in fluent bilinguals (e.g., De Groot & Poot, 1997; La Heij, Hooglander, Kerling, & van der Velden, 1996). However, Kroll has made the case that translation to the dominant language is word mediated in fluent late bilinguals when they remain dominant in their native language, and her revised hierarchical model provides a mechanism for the formation of word-to-word associations (Kroll & Stewart, 1994; Sholl et al., 1995). However, when corresponding words in two languages are learned in close temporal proximity, the basis of forming such associations is eliminated, and therefore the model is not meant to apply to early bilinguals in a bilingual immersion context, such as the participants in the present study. Therefore, translation was expected to be concept mediated in both directions, but predictions based on both methods of translation were considered and tested.
The preceding descriptions of picture naming and translation processes are intentionally oversimplified. The sets of processes addressed here have been further decomposed in research designed to investigate the nature of object recognition, language comprehension, and language production. In these areas, a critical issue has been the extent to which various subprocesses occur sequentially or overlap in time, but the present study neither depends on nor attempts to address the existence, nature, or timing of the component subprocesses. In the present investigation, it is assumed that picture-identification processes are initiated before word-retrieval processes in picture naming, and that word-comprehension processes are initiated before word-retrieval processes in translation. However, it is not necessary to assume that one set of processes is completed before the next set begins.

Several recent studies have been interpreted as evidence that when bilinguals name pictures or words in one target language, activation also spreads to the nontarget language, particularly when the target language is the non-dominant language. For example, when distractor words were superimposed on pictures to be named, translations of the target response facilitated naming (Costa, Miozzo, & Caramazza, 1999), and words that were phonologically similar to the translation interfered with naming (Hermans, Bongaerts, de Bot, & Schreuder, 1998). Picture naming has also been shown to be slower for noncognates than for cognates in bilinguals but not in monolinguals, suggesting that in the case of noncognates, the phonology of the nontarget language competes with the phonology of the target language (Costa, Caramazza, & Sebastian-Galles, 2000). When judging whether a particular phoneme was in the name of a picture, phonemes occurring in the nontarget translation were slower to reject than control phonemes, presumably because of implicit activation of the nontarget language (Colomé, 2001). Thus, incidental activation may have consequences for immediate processing of both the target and nontarget language. However, there has been no evidence that such implicit activation of the nontarget language can impact processing of an item after a delay of several minutes filled with intervening trials. Because of the potential implications for repetition priming, this question was explicitly tested and is addressed in the General Discussion section.

The Present Study

The purposes of the present study were to determine whether practice of common processes would lead to symmetric or asymmetric priming effects across tasks and to determine the locus at which difficulty affects priming magnitude. To examine this issue, we applied and tested an explicit model based on the principle of transfer-appropriate processing, in which the practice of processes shared by study and test tasks is assumed to be the primary basis of repetition priming. Tasks are defined in terms of their component processes, which when successfully completed, lead from a stimulus to an overt response. Processes are conceptualized in a manner similar to those used in critical path networks (Townsend & Schweickert, 1989) and in other mathematical models of picture and word processing (e.g., Theios & Amrhein, 1989). First, a process is defined in terms of its start and end points and the subprocesses between them. The start point, end point, and the path used to traverse these points must match for two processes to be considered equivalent, although only the path is used to predict priming. Picture identification processes will be considered equivalent if they start with the same stimulus and end with access to the same concept, and word retrieval processes will be considered equivalent if they start with the same concept and end with the same overt response.

Applying a selective influence to a process will facilitate or inhibit its execution, resulting in a corresponding decrement or increment in response time (as in critical path networks). Prior practice of processes necessary to complete a test task will elicit facilitation, or repetition priming (so long as the practiced process or processes are not overlearned, in which case repetition would have no detectable effect). The requirement that the processes be necessary components of the test task is consistent with Franks et al.’s (2000) conclusion that only intentional processes required at test will be subject to observable repetition priming. This repetition priming will manifest itself as a decrease in response time (or an increase in accuracy). When one process or set of processes necessary for task completion is practiced, and other necessary processes are not practiced, that practice will exert a selective influence on the practiced processes when the item is repeated. This selective practice can be accomplished by prior completion of a task that has that process in common with the target task. The magnitude of facilitation between two tasks that share a necessary process should remain constant regardless of the assignment of tasks to prime or test status. If practice of shared processes is assumed to be the primary basis of facilitation, then it can be inferred that when there is more shared processing, there will be more facilitation. Taking the logic a step further, it can be inferred that when the shared processes are more difficult, there will be more shared processing and therefore stronger priming. Thus, process-based difficulty effects on priming can be derived naturally from transfer-appropriate processing logic. However, it has not yet been determined empirically whether the difficulty effects on repetition priming are based on the difficulty of shared processes or on the overall difficulty of the test task.

The use of both English and Spanish response languages allows for testing this model and, as a more general principle, the idea that difficulty influences priming magnitude only at the level of the component process. Under this model, tasks that share an equivalent process should prime each other symmetrically, and more difficult shared processes should exhibit more priming. In bilinguals, language-general shared processes should prime each other symmetrically, but language-specific processes should exhibit more priming when using the nondominant language. Specifically, priming of picture identification processes should not depend on the language or modality of the response. In contrast, because word retrieval processes are more difficult in the nondominant language, word retrieval is expected to exhibit more priming when responses are given in the nondominant language. Specifically, within a language, two tasks requiring word retrieval ought to prime each other symmetrically. Experiment 1 focuses on picture-identification processes, and Experiment 2 focuses on word-retrieval processes.

The use of English and Spanish response languages in combination with the repetition priming paradigm also allows for testing hypotheses about bilingual lexical access. Experiment 1 and the combined results are used to determine whether incidental activation of the nontarget language during naming affects performance after a delay of several minutes. Experiment 2 and the combined
results are used to test whether translation to the dominant language is concept mediated or word mediated.

**Experiment 1**

Experiment 1 deals with priming of equivalent picture identification processes across picture naming tasks in English and Spanish. Priming of picture naming based on facilitation of picture identification processes has been demonstrated using encoding tasks that require perceiving and identifying pictures but not retrieving their names. Making a semantic or nonsemantic judgment about a picture facilitates later naming relative to new items (Carroll, Byrne, & Kirsner, 1985), as do verifying a picture’s category membership (Vaidya et al., 1998) and naming the picture in a different language (Francis, 1998; Francis et al., 2002; Hernandez & Reyes, 2002). Experiment 1 examined priming of picture naming within and between languages. When picture naming is repeated with the same response language, all processes are repeated and could potentially exhibit priming. In contrast, when the response language changes from study to test, picture identification processes are the only intentional processes repeated, as illustrated in Figure 1A, and those processes ought to be facilitated.

The primary set of predictions was derived for the case in which only word retrieval processes in the language selected for production in an encoding phase block would impact later processing or repetition priming. In this case, picture identification is the only set of shared processes that will exhibit priming across languages. If difficulty affects priming only at the process level, between-language priming ought to be symmetric, whereas within-language priming ought to be greater in the nondominant language. If difficulty operates at the task level, then both between-language priming and within-language priming should be greater when final naming is in the nondominant language because it is a slower, more difficult task. The greater difficulty of picture naming in the nondominant language is supported by previous research showing longer response times and higher error rates in the nondominant language (Chen, 1990; Chen & Leung, 1989; Francis, 1998; Kroll & Curley, 1988; Potter et al., 1984; Sholl et al., 1995).

Both intentional and incidental processes completed at study may elicit facilitation of intentional processes at test (Franks et al., 2000). Therefore, we must consider the possibility that processes that are incidental to naming in the study language but necessary for naming in the test language may also contribute to priming. If the nontarget language is incidentally activated in the prime phase, as suggested by Costa et al. (1999, 2000), and this activation impacts processing at test, the set of predictions is different. In between-language conditions, not only would the prime phase provide practice of picture-identification processes, but also practice of some word-retrieval processes in the nontarget language, which becomes the target response language in the test phase. If the nontarget language were activated for naming in both languages, the expected results under either process difficulty or task difficulty would be greater priming from the dominant to the nondominant language than from the nondominant to the dominant language. For process difficulty, this pattern would derive from the greater difficulty of word retrieval in the nondominant language, and for task difficulty it would derive from the greater difficulty of the picture-naming task in the nondominant language. If the nontarget language were only activated when naming in the nondominant language, the expected results under process difficulty would be greater priming from the nondominant to the dominant language because of the extra practice with dominant-language word retrieval. Under task difficulty, the greater difficulty of naming in the nondominant language and the extra practice with dominant-language word retrieval would operate in opposite directions, thus making the direction of the net effect unclear.

We have previously demonstrated priming between languages in picture naming, stronger within-language priming than between-language priming, and stronger within-language priming in the nondominant than in the dominant language (Francis, 1998; Francis et al., 2002). However, in those experiments, power was not concentrated in the conditions critical to testing the symmetry of priming between languages. Another recent study of bilingual picture naming also appears to demonstrate priming between languages and suggests that within-language priming is stronger in

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**Figure 1.** Shared processes in Experiments 1 and 2. A: Picture naming in the dominant language and picture naming in the nondominant language share picture-identification processes. B: Picture naming in the nondominant language and translation to the nondominant language share word retrieval processes. Quotation marks indicate overt responses.
the nondominant language (Hernandez & Reyes, 2002). In Experiment 1 of the present study, the power of 60 bilingual participants, each naming 53 items per condition, was concentrated into detecting priming asymmetries, using a completely within-subjects design.

Method

Participants and bilingual environment of study. Participants were 60 self-identified Spanish–English bilinguals (39 women, 21 men) ranging in age from 17 to 43 (\(Mdn = 19\)), all reporting Hispanic ethnicity. All were undergraduate students at the University of Texas at El Paso who participated as part of a course research requirement. None had previously participated in an experiment involving the critical picture stimuli. Most (52) of the students indicated that they had learned Spanish first, 2 had learned English first, and 6 had learned both Spanish and English simultaneously from early childhood. 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 normative age for children to begin kindergarten in the United States. An examination of the ages indicated for second language acquisition revealed that 30 were 5 years old or younger when they began to learn their second language, 27 were from 6 to 10 years old, 2 were from 10 to 15 years old, and one was 16 or older. They had an average 15 years of experience with their second language. According to self-ratings of relative proficiency, 41 were classified as English dominant and 19 were classified as Spanish dominant. On average, they reported that over the preceding month they had used English 52.5% of the time, Spanish 34.6% of the time, and a mixture (code switching) 12.9% of the time. This pattern corresponded to using the dominant language 58.6% of the time and the nondominant language 28.5% of the time, indicating that the participants used both languages on a regular basis. Thirteen other students completed the protocol but were excluded and replaced because of low accuracy (less than 50%) in their nondominant languages.

The student participants were residing in the U.S.–Mexico border region of El Paso, Texas, and Juárez, Chihuahua, Mexico, and therefore had regular exposure to both English and Spanish. The linguistic environment of the city of El Paso is bilingual, such that in almost any public area, local business, or the university, both languages are spoken. The university is approximately 70% Hispanic, with an additional 10% of students being Mexican nationals, many of whom commute across the border daily to attend class. Student interactions on campus are often in Spanish, and introductory courses in most departments are offered in Spanish as well as English.

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

Design. Experiment 1 had a 3 (initial phase presentation) \(\times\) 2 (final response language) within-subjects factorial design. In the initial phase, items were presented for naming in English, for naming in Spanish, or not at all, and in the final phase language was either English or Spanish. The order of languages was counterbalanced across participants.

Stimuli. The experimental stimuli were 318 pictures selected primarily from the Snodgrass and Vanderwart (1980) and Abbate (1984) sets. The pool of pictures was selected to include only items that were identifiable and nonredundant in both English and Spanish and that were not judged to be too difficult. The median Kučera and Francis (1967) frequency of the expected English names of the pictures was 13 per million. The mean letter lengths of the expected English and Spanish responses were 5.7 and 6.3, respectively. For the subset of pictures (114) that came from the Snodgrass and Vanderwart set, the mean percentage name agreement was 90.2% for English monolinguals naming in English and 88.0% for Spanish monolinguals naming in Spanish (Goggin, Estrada, & Villarreal, 1994). The full set of 318 pictures was randomly divided into 6 sets of 53 pictures. Each set represented one experimental condition, and the assignment of item sets to conditions was counterbalanced across participants using a Latin square.

Procedure. Participants were tested individually in sessions lasting approximately 45 min. Before beginning the experimental trials, participants were given practice using the microphone and voice-relay equipment for a number-naming task. For the experimental task of picture naming, each trial began with presentation of the picture, which remained on the screen until a vocal response was registered, and then there was a 1,250-ms delay before the next picture appeared. Vocal response times were recorded by using the microphone and button-box apparatus, and the experimenter noted all unexpected responses and timing errors (failures to activate the voice relay with the response and accidental activation of the voice relay before the response). At the beginning of each block of picture naming trials, instructions were given in the corresponding language. In the encoding phase, there was one block of English and one block of Spanish picture-naming trials, with each block beginning with four filler items and continuing with 106 experimental items presented in a random sequence. The test phase likewise had one block of English and one block of Spanish picture-naming trials, with each block consisting of 159 experimental items presented in random sequence. (One third of those items had been named in English, one third had been named in Spanish, and one third had not been presented in the encoding phase.) In both the encoding and test phases, participants were given a short break halfway through each block of trials, and language order was counterbalanced across participants. Upon completion of the response-time tasks, participants completed a language background questionnaire and were debriefed.

Results

Data processing. Because analysis would focus on response times in the test phase of the experiment, it was important to eliminate any invalid test-phase trials before extracting the condition means for each participant. Out of a total of 318 test-phase trials, on average 11.8% (SD = 4.9%) were removed as naming-error responses (including don’t know responses), 0.7% were removed as machine-timing errors, and 9.6% were removed as spoiled trials. Spoiled trials had correct test-phase responses that were correctly timed, but the prime status of the item was compromised. Trials were considered spoiled if the prime-phase response was unacceptable (5.4%), acceptable but inconsistent with the test-phase response (1.6%), or had a machine-timing error (0.8%), or if the answer or its translation was given as an error
response to an earlier item (1.8%). (Prime-phase items corresponding to these excluded items were also excluded from the prime-phase analysis.) Items with response times greater than 5,000 ms, less than 200 ms, or more than 2 SDs from the mean were removed as outliers, which resulted in the exclusion of 4.2% of the trials. Thus, on average, 73.8% of the test-phase trials were retained for the response-time analysis, which left a mean of 39 items per condition per participant.

Prime-phase analysis. Picture-naming response times and error rates for the two languages were compared by using dependent-samples *t* tests. All inferential statistical tests in this study were bidirectional with *α* = .05. Consistent with the fact that most of the participants rated themselves as English dominant, picture-naming responses were faster in English (M = 1,037, SD = 246) than in Spanish (M = 1,172, SD = 241), *t*(59) = 3.35, *p* < .01. Error rates were also lower for English (M = 10.1%, SD = 6.3%) than for Spanish (M = 18.3%, SD = 9.5%), *t*(59) = 5.03, *p* < .01. Because the dominant language is an important predictor of response time and was also to be used as a predictor of priming, English and Spanish responses were recoded to reflect the dominant and non-dominant languages indicated by participants’ self-reported relative proficiency ratings. As expected, picture-naming response times were longer in the nondominant language (M = 1,227, SD = 258) than in the dominant language (M = 982, SD = 175), *t*(59) = 8.13, *p* < .01. Error rates were also higher in the nondominant language (M = 19.5%, SD = 9.2%) than in the dominant language (M = 8.8%, SD = 4.6%), *t*(59) = 7.82, *p* < .01. This recoding is important when some bilinguals are dominant in one language and others are dominant in the other language, as is the case here. For 90% of the participants, the self-reported dominant language was also the language in which pictures were named faster.

Test-phase analysis. Mean test-phase response times for each experimental condition are shown in Table 1, along with priming effects and error rates. Test-phase response times were analyzed by using a 3 (study condition) × 2 (test language) analysis of variance (ANOVA), with relevant planned comparisons. As in the prime phase, response times for new items were longer in the nondominant language (M = 1,334, SD = 319) than in the dominant language (M = 1,110, SD = 187), *F*(1, 59) = 41.34, *MSE* = 36,437, *p* < .01.

Overall, repeated items were named faster than new items, *F*(1, 59) = 219.80, *MSE* = 14,501, *p* < .01. As expected, planned comparisons showed that priming for repeated relative to new items was reliable for all of the four language combinations (all *p* < .01). As illustrated in Figure 2, priming was greater when the response language matched from study to test, *F*(1, 59) = 144.55, *MSE* = 42,498, *p* < .01. This was true for both test-phase response languages, dominant: *F*(1, 59) = 70.08, *MSE* = 4,821, *p* < .01; nondominant: *F*(1, 59) = 78.18, *MSE* = 18,397, *p* < .01. This effect was stronger in the nondominant language than in the dominant language, as indicated by a significant interaction between response language and language match, *F*(1, 59) = 15.59, *MSE* = 12,252, *p* < .01. Same-language priming was greater in the nondominant language (M = 341) than in the dominant language (M = 221), *F*(1, 59) = 14.97, *MSE* = 28,528, *p* < .01. However, the magnitude of different-language priming did not differ across response languages, *F*(1, 59) = 0.05, *MSE* = 26,221, *p* = .83. The significant interaction indicates that these two patterns differed reliably. Thus, priming within a language was stronger for the nondominant language, but priming between languages was symmetric across the two response languages. Similar patterns of response time and priming effects were observed in an analysis according to English and Spanish language,\(^2\) as well as in separate analyses of English-dominant and Spanish-dominant participants.

Error rates also varied as a function of language and repetition condition and were analyzed by using a 3 (study condition) × 2 (test language) ANOVA. As in the prime phase, new-item error rates were higher in the nondominant language than in the dominant language, *F*(1, 59) = 42.90, *MSE* = 17.364, *p* < .01. Repeated items named in the same language at study and test exhibited lower error rates than new items, *F*(1, 59) = 10.03, *MSE* = 5.494, *p* < .01, and repeated items named in different languages at study and test, *F*(1, 59) = 7.33, *MSE* = 8.597, *p* < .01. However, error rates for repeated items named in a different language at study and test did not differ from those of new items, *F*(1, 59) = 0.04, *MSE* = 6.479, *p* = .84. The magnitudes of these repetition effects did not differ across response languages, *F*(1, 59) = 0.25, *MSE* = 17.758, *p* = .62. This pattern of error rates supports the idea that the main source of error or naming failure is in the word retrieval process (rather than picture identification).

**Table 1**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dominant RT (ms)</th>
<th>Dominant ER (%)</th>
<th>Nondominant RT (ms)</th>
<th>Nondominant ER (%)</th>
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<tr>
<td>New items</td>
<td>1,110</td>
<td>7.7</td>
<td>1,334</td>
<td>17.1</td>
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<tr>
<td>Same language</td>
<td>889</td>
<td>5.6</td>
<td>994</td>
<td>15.6</td>
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<tr>
<td>Priming</td>
<td>221**</td>
<td>2.1*</td>
<td>341**</td>
<td>1.5</td>
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<tr>
<td>Different language</td>
<td>995</td>
<td>7.6</td>
<td>1,213</td>
<td>17.4</td>
</tr>
<tr>
<td>Priming</td>
<td>115**</td>
<td>0.1</td>
<td>122**</td>
<td>−0.3</td>
</tr>
</tbody>
</table>

*Note.* RT = response time; ER = error rate. *p* < .05. ** *p* < .01.

**Discussion**

Picture naming exhibited substantial repetition priming in both the dominant and nondominant languages, whether the language matched from study to test or not, but within-language priming was stronger than between-language priming. Within-language priming was stronger in the nondominant language than in the dominant language, but between-language priming was equivalent for the two languages. The symmetric priming between languages supports the idea that the shared processes determine the magnitude of priming, but overall task difficulty does not influence priming magnitude when the set of processes primed is held constant across tasks. Here, picture identification was necessary.

\(^2\) New-item response times in English (M = 1,133) were faster than new-item response times in Spanish (M = 1,312), reflecting the higher proportion of English-dominant participants. Within-language priming was stronger in Spanish (M = 326) than in English (M = 236), but between-language priming was similar for the English–Spanish (M = 118) and Spanish–English (M = 119) conditions.
for naming in both languages, and its susceptibility to priming did not differ across response languages. Although previous research suggests that activation of the nontarget language during picture naming may occur and influence immediate processing (Colomé, 2001; Costa et al., 1999, 2000; Hermans et al., 1998), there was no evidence here that any such activation at study influenced repetition priming. Otherwise, priming between languages would have been asymmetric. (In the General Discussion section, this issue will be addressed in more detail.)

Because priming of picture naming between languages is based on shared picture-identification processes, the additional priming obtained in within-language conditions can reasonably be attributed to the repetition of word-retrieval processes. The additional priming obtained when the language matched was much greater for the nondominant language (219 ms) than for the dominant language (106 ms), which indicates that word retrieval processes are more susceptible to priming in the nondominant language. Because word retrieval is more difficult in the nondominant language, this result is consistent with process-based difficulty effects.

Experiment 1 shows that priming of language-general picture-identification processes across picture-naming tasks in English and Spanish. Experiment 2 examines priming of word retrieval, the other set of processes required for picture naming. Previous studies have demonstrated priming of word selection and production processes in picture naming by using encoding tasks that require selecting and articulating the names of the pictures without presentation of the target picture itself. Generating a picture’s name in response to a definition facilitates later naming relative to new items (Lee & Williams, 2001; Monsell et al., 1992; Wheeldon & Monsell, 1992). This priming cannot be due merely to activation of the concept, because in bilinguals, producing a word in response to a definition in one language does not prime picture naming in the other language (Lee & Williams, 2001; Monsell et al., 1992). Picture naming is also facilitated by generating the picture’s name in response to a different exemplar of the object (Biederman & Cooper, 1991; Stankiewicz et al., 1998) or as a translation response (Francis, 1998; Francis et al., 2002). For Experiment 2, translation was chosen as the critical comparison task because it can be easily timed by using the same procedures as for picture naming and it consistently takes longer than picture naming. Also, the word-retrieval processes of translation are facilitated by previous picture naming, at least when responding in the nondominant language (Sholl et al., 1995).

As illustrated in Figure 1B, picture naming in the nondominant language and translation from the dominant to the nondominant language share a common process of word retrieval in the nondominant language. Similarly, picture naming in the dominant language and translation from the nondominant to the dominant language share a common process of word retrieval in the dominant language if it is assumed that the translation is concept mediated. Therefore, when the response language is held constant
from study to test, only these word-retrieval processes should be primed across translation and picture-naming tasks.

Experiment 2 was designed to determine whether common word-retrieval processes lead to symmetric or asymmetric priming effects across picture-naming and translation tasks and whether the more difficult word-retrieval processes in the nondominant language are more susceptible to priming than word retrieval in the dominant language. As explained in the introduction, translation in both directions was expected to be concept mediated in the test population. However, predictions were derived that could separate process and task difficulty mechanisms, first assuming that translation in both directions was concept mediated, and then assuming that translation to the dominant language was word mediated. The combination of conditions included also allowed us to test whether translation to the dominant language was concept mediated or word mediated.

The first set of predictions was derived assuming concept-mediated translation in both directions. Under these circumstances, if difficulty operates at the process level, picture naming and translation should prime each other equally within each response language. However, priming should be stronger when the shared word-retrieval process is more difficult, specifically when responses are given in the nondominant language. The assumption that word retrieval is more difficult in the nondominant language is supported by previous research showing slower response times and higher error rates for naming pictures in the nondominant language (e.g., Chen, 1990; Potter et al., 1984; Sholl et al., 1995). There is a corresponding tendency for slower responses in translating to the nondominant language (e.g., Kroll & Stewart, 1994; Miller & Kroll, 2002; Potter et al., 1984; Sholl et al., 1995). The prediction that word-retrieval processes will exhibit more priming in the nondominant language is also supported by previous research showing that both priming from picture naming to translation (Sholl et al., 1995) and priming from translation to picture naming (Francis, 1998) were stronger in the nondominant language. If difficulty operates at the task level, picture naming should prime translation more than translation primes picture naming because translation is the more difficult task, as indicated by its longer response time to new items (e.g., Chen, 1990; Francis, 1998; Potter et al., 1984).

A second and different set of predictions was derived assuming concept-mediated translation to the nondominant language and word-mediated translation to the dominant language. First, within the process-based difficulty effects, facilitation of translation due to prior picture naming would be minimal when responding in the dominant language. The only processes of word-mediated translation that would be practiced by prior picture naming are those that occur after the appropriate word has been retrieved, namely articulating the appropriate phonology. An upper limit on the magnitude of such priming might be that obtained with repeated word naming or the magnitude of priming in word naming after naming the corresponding picture. These effects have had magnitudes of 30 ms or less (Durso & Johnson, 1979; Vriezen et al., 1995). Also, the priming between picture naming and translation might be expected to be asymmetric when responding in the dominant language. That is, when translation is the prime task and picture naming is the test task, after traversing the word-to-word link from the nondominant language to the dominant language in translation, incidental automatic access to the concept may occur. Such access would provide a further basis for facilitation for later picture naming in addition to the small effect based on repeated articulation of the phonology. If difficulty effects operate at the task level, then with word-mediated translation, the priming effects in the dominant language would be expected to show the opposite pattern, more priming for translation than picture naming, because translation takes substantially longer than picture naming when responding in the dominant language (Francis, 1998; Francis et al., 2002; Kroll & Curley, 1988; Potter et al., 1984).

Although previous research has demonstrated that translation facilitates picture naming (Francis, 1998; Francis et al., 2002) and picture naming facilitates translation (Sholl et al., 1995), the relative magnitudes of these effects are not clear because these two types of priming have never been compared directly within a single study. In Experiment 2, we make this direct comparison by measuring priming between translation and picture naming in the dominant and nondominant languages. The power of 96 bilingual participants, each naming or translating 25 items per condition, was concentrated into the conditions necessary to testing the model predictions, using a completely within-subjects design.

Method
Participants. Participants were recruited from the same population as in Experiment 1. They included 96 self-identified Spanish–English bilinguals (61 women, 35 men) ranging in age from 17 to 39 years old (Mdn = 19), all reporting Hispanic ethnicity. All were undergraduate or graduate students at the University of Texas at El Paso who participated for part of a course research requirement or for a payment of $5. None had previously participated in an experiment involving the critical picture stimuli. Almost all (94%) indicated that they had learned Spanish first, and all but one of the remaining participants had learned both Spanish and English simultaneously from early childhood. The mean age at which participants reported beginning to learn the second language was 8 years old, and the modal age was 4. Thirty-four indicated that they were 5 years old or younger when they began learning the second language, 36 were from 6 to 10 years old, 15 were from 11 to 15 years old, and 8 were 16 or older (3 other participants did not report this information). They had on average 13 years of experience with their second language. According to self-reported relative proficiency ratings, 57 were classified as Spanish dominant and 39 were classified as English dominant. On average, they reported that over the preceding month, they had used English 48.3% of the time, Spanish 42.0% of the time, a mixture 8.8% of the time, and another language 0.9% of the time. (Four students were excluded from these means because their percentages did not add up to 100%). This pattern corresponded to using the dominant language 54.9% of the time and the nondominant language 35.4% of the time. Twenty-two other students completed the procedures but were excluded and replaced because of low accuracy in their nondominant languages.

Design. Experiment 2 had a 2 (final task) × 2 (final response language) × 2 (new or old) within-subjects factorial design. The final task was either picture naming or translation, with the final response language either English or Spanish. Half of the items in each final-phase naming and translation block were those previously translated or named, and half were new items. Corresponding pairs of picture-naming and translation items always had the same response language. The order of the tasks and languages was counterbalanced across participants.

Materials. The experimental stimuli consisted of 200 pictures selected from the Snodgrass and Vanderwart (1980) set and their names in English and Spanish. These items were selected with the requirement that their pictures and names were identifiable and nonredundant in both English and Spanish; items thought to be too difficult and items previously shown to have low name agreement in English or Spanish were also avoided. Target
picture-naming responses, translation stimuli, and target translation responses were the most frequent English and Spanish responses to the Snodgrass and Vanderwart pictures in a norming study conducted with students in the El Paso–Juárez region (Goggin et al., 1994). The median Kučera and Francis (1967) frequency of the expected English names of the pictures was 14 per million. The mean letter lengths of the expected English and Spanish responses were 5.6 and 6.1, respectively. The mean percentage name agreement was 91.9% for English monolinguals naming in English and 89.8% for Spanish monolinguals naming in Spanish (Goggin et al., 1994). The items were randomly assigned to 8 sets of 25. These 8 sets corresponded to the 8 experimental conditions and the assignment of item sets to experimental conditions was counterbalanced across participants by using a Latin square.

Procedure. Participants were tested individually by a bilingual experimenter in sessions lasting approximately 30 min, with the same apparatus as in Experiment 1 (except that the computer was a Power Macintosh). Before beginning the experiment, participants were given practice using the voice-relay microphone with a number-naming task. Each experimental picture-naming or translation trial began with presentation of the picture or word stimulus, which remained on the screen until a vocal response was registered, and then there was a 1.250-ms delay before the next stimulus appeared. Vocal response times were recorded by using the button box, and the experimenter noted unexpected responses and timing errors on a checklist of expected responses. Before each block of experimental trials, instructions were given in the required response language. Participants completed eight blocks of trials. The four prime-phase blocks each consisted of 3 practice trials and 25 experimental trials presented in random order; the four test-phase blocks each consisted of 50 experimental trials presented in random order, half of which involved items presented in the first phase. Upon completion of the response-time tasks, participants completed a language background questionnaire and were debriefed.

Results

Data processing. Invalid test-phase trials were eliminated before extracting condition means for each participant, as in Experiment 1. The test phase had 200 trials, of which 2 trials (1%) were removed for all participants because of an inadvertent repetition of a Spanish translation. In the test phase, an average of 15.1% of trials (SD = 5.5%) were removed because of naming or translation errors, 1.5% for machine-timing errors, and 6.8% for spoiled trials. Spoiled trials included trials for which the prime-phase response was unacceptable (3.6%), acceptable but inconsistent with the test-phase response (0.7%), or had a machine-timing error (0.8%), and trials for which the answer or its translation was given as an error response to an earlier item (1.7%). Outlier removal (absolute and standard-deviation-based) resulted in the exclusion of 4.7% of the trials. Thus, on average, 70.9% of the test phase trials were retained for the response time analysis, which left a mean of approximately 18 trials per condition per participant.

Prime-phase analyses. Mean picture-naming and translation response times and error rates in the prime phase are shown in Table 2. As in Experiment 1, English and Spanish data were recoded to reflect the dominant and nondominant languages indicated by the self-report measure. Prime-phase response times and error rates were analyzed by using two separate 2 (task) × 2 (response language) ANOVAs. Response times were faster overall for picture naming than for translation, F(1, 95) = 47.38, MSE = 34,881, p < .01. This advantage for picture naming was reliable in both the dominant and the nondominant language, dominant: F(1, 95) = 54.34, MSE = 33,886, p < .01; nondominant: F(1, 95) = 5.84, MSE = 36,414, p = .02. However, the effect was stronger in

Table 2
Test-Phase Response Times, Error Rates, and Priming in Experiment 2

<table>
<thead>
<tr>
<th>Condition</th>
<th>Dominant</th>
<th>Nondominant</th>
<th>Dominant</th>
<th>Nondominant</th>
</tr>
</thead>
<tbody>
<tr>
<td>New item naming</td>
<td>1.104</td>
<td>1.293</td>
<td>14.4</td>
<td>13.2</td>
</tr>
<tr>
<td>Translation</td>
<td>1.004</td>
<td>1.064</td>
<td>12.6</td>
<td>12.2</td>
</tr>
<tr>
<td>Priming</td>
<td>101**</td>
<td>230**</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>New item translation</td>
<td>1.315</td>
<td>1.368</td>
<td>20.3</td>
<td>18.5</td>
</tr>
<tr>
<td>Priming</td>
<td>1.218</td>
<td>1.141</td>
<td>15.9</td>
<td>14.1</td>
</tr>
<tr>
<td>Translation</td>
<td>96**</td>
<td>227**</td>
<td>4.4*</td>
<td>4.4*</td>
</tr>
</tbody>
</table>

Note. RT = response time; ER = error rate.
*p < .05. **p < .001.

Results. RT = response time; ER = error rate.
the dominant language, as indicated by a significant interaction, F(1, 95) = 11.33, MSE = 35,418, p < .01. Picture naming was faster in participants’ self-reported dominant language (M = 973, SD = 181) than in the nondominant language (M = 1,124, SD = 231), F(1, 95) = 32.66, MSE = 33,270, p < .01. For 73% of participants, the self-reported dominant language was also the faster language for picture naming. (This agreement rate is lower than in Experiment 1, possibly reflecting the lower number of trials.) Translation showed a numerical pattern in the same direction, with faster responses for translation from the nondominant to the dominant language (M = 1,169, SD = 270) than from the dominant to the nondominant language, but it did not approach significance (M = 1,190, SD = 268), F(1, 95) = 0.56, MSE = 38,491, p = .46.

Error rates were higher for translation (M = 19.9%, SD = 8.5%) than for naming (M = 13.3%, SD = 6.2%), F(1, 95) = 68.73, MSE = 3.712, p < .01. However, error rates did not differ across languages, F(1, 95) = 0.148, MSE = 11.033, p = .70, and there was no indication of a Task × Language interaction, F(1, 95) = 0.005, MSE = 4.639, p = .94.

Test-phase analyses. Test-phase response times, error rates, and priming effects are shown in Table 2. In the test phase, response times for new items were again faster for picture naming than for translation, F(1, 95) = 36.72, MSE = 52,876, p < .01. This effect was reliable in both the dominant language, F(1, 95) = 60.34, MSE = 35,192, p < .01, and the nondominant language, F(1, 95) = 5.01, MSE = 52,622, p = .03. The effect was stronger in the dominant language, as indicated by a significant interaction, F(1, 95) = 12.75, MSE = 34,939, p < .01. Response times to new items were reliably faster in the dominant than in the nondominant language for naming, F(1, 95) = 55.56, MSE = 30,893, p < .01, and this trend approached statistical significance for translation, F(1, 95) = 3.26, MSE = 41,161, p = .07.

Overall, responses to repeated items were faster than responses to new items, F(1, 95) = 250.78, MSE = 20,431, p < .01. Priming of repeated relative to new items was reliable in all four final Task × Language combinations (all ps < .01). As shown in Figure 2, priming effects were stronger in the nondominant language than in the dominant language, as indicated by a main effect of response language, F(1, 95) = 43,603, MSE = 37,046, p < .01. This effect held for both picture naming, F(1, 95) = 25.55, MSE =
Implications for Bilingual Language Processing. 
mediated translation is discussed and dismissed in the section 
effect could reflect a combination of concept-mediated and word-
gests that translation to the dominant language was concept me-
observed when responding in the dominant language, which sug-
substantial priming from picture naming to translation was also 
Sholl et al. (1995). However, in contrast to the Sholl et al. study, 
effects in our previous research (Francis, 1998; Francis et al., 
production processes were facilitated equivalently across tasks, 
the difficulty of the specific processes facilitated. Here, word 
priming effects were not greater for translation. It is clear, there-
error rate, 
There was also no detectable interaction of task and language on 
accuracy. These priming effects were 
for naming in the dominant language, 
MSE = 4.461, p = .70.

The most interesting finding in the error-rate analysis was that 
error rates were lower for repeated items than for new items, F(1, 
response language, F(1, 95) = 1.23, MSE = 10.968, p = .27. 
There was also no detectable interaction of task and language on 
error rate, F(1, 95) = 0.149, MSE = 4.461, p = .70.

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There was also no detectable interaction of task and language on 
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Discussion

Priming between translation and picture-naming tasks was 
substantial in both response languages. The findings of priming from 
translation to picture naming are consistent with the corresponding 
effects in our previous research (Francis, 1998; Francis et al., 
2002). The finding of priming from picture naming to translation 
when responding in the nondominant language replicates that of 
Sholl et al. (1995). However, in contrast to the Sholl et al. study, 
substantial priming from picture naming to translation was also 
observed when responding in the dominant language, which sug-
gests that translation to the dominant language was concept me-
diated. (The possibility that this smaller but substantial priming 
effect could reflect a combination of concept-mediated and word-
mediated translation is discussed and dismissed in the section 
Implications for Bilingual Language Processing.)

The most important findings were that priming was symmetric 
across picture naming and translation tasks within each response 
language and that priming was stronger when responses were 
given in the nondominant language. Even though response times 
to new items were longer for translation than for picture naming, 
the priming effects were not greater for translation. It is clear, there-
fore, that the magnitude of priming is not a monotonic function of 
the overall task difficulty. Instead, priming magnitude depends on 
the difficulty of the specific processes facilitated. Here, word 
production processes were facilitated equivalently across tasks, 
with more facilitation observed when it was necessary to retrieve 
words in the more difficult nondominant language.

Whereas Experiment 1 had an indirect measure of word retrieval 
priming in picture naming (the increment in priming when the 
response language matched from study to test), the measure of 
word retrieval priming in Experiment 2 was direct. A comparison 
of these effects shows that in the dominant language, the magni-
tudes of the indirect and direct measures of priming were 106 ms 
and 101 ms, respectively. In the nondominant language, the magni-
tudes were 219 ms and 230 ms, respectively. Thus, the indirect 
and direct measures yielded similar estimates of word-retrieval 
priming.

General Discussion

Across two experiments, we tested the idea that equivalent 
processes would prime each other equivalently to clarify how 
transfer appropriate processing, process difficulty, and task difficul-
ty influence repetition priming. Priming of picture-
identification processes was symmetric across response languages 
in Experiment 1. Priming of word-retrieval processes was 
symmetric across naming and translation tasks within each language 
in Experiment 2. In contrast, Experiment 1 showed indirectly and 
Experiment 2 showed directly that word retrieval is primed asym-
metrically across languages, with more priming for nondominant-
language word retrieval.

The lack of statistically reliable asymmetries in priming be-
tween tasks thought to share a process does not in and of itself 
support the conclusion that these priming effects are symmetric. 
However, several characteristics of the data do strengthen this 
conclusion. First, the mean priming asymmetry magnitudes were 
miniscule in an absolute sense, with means of 6.5 ms for picture-
identification processes, 4.3 ms for word retrieval in the dominant 
language, and 3.0 ms for word retrieval in the nondominant lan-
guage. The corresponding effect sizes (Cohen’s d) were .028, .016, 
and .009, respectively. The mean priming asymmetry magnitudes 
were also small relative to the sizes of the priming effects them-
theselves. The mean asymmetry in priming of picture comprehension 
was only 5.5% the magnitude of the mean picture-identification 
priming effect (averaged across response languages). The mean 
asymmetry in priming of word retrieval in the dominant language 
was 4.4% the magnitude of the corresponding priming effect 
(averaged across tasks). For priming of word retrieval in the 
nondominant language, this percentage was 1.3%. Finally, the 
mean priming asymmetry magnitudes were small relative to the 
asymmetries in priming across languages. In Experiment 1, the 
asymmetry in priming of picture identification using between-
language priming was only 5.4% the magnitude of the asymmetry 
between languages in within-language priming. In Experiment 2, 
the asymmetry in priming of word retrieval across tasks was only 
2.8% the magnitude of the corresponding difference in priming 
between the dominant and nondominant response languages.

Bases of Repetition Priming

In both experiments, pairs of tasks requiring common picture-
identification or word-retrieval processes primed each other sym-
metrically. This symmetric priming was consistent with the 
process-based difficulty effects derived in our literal transfer-
appropriate processing model. However, the symmetric priming results are inconsistent with the pattern of priming expected for task-based difficulty effects. If overall task difficulty had been an important determinant of priming, then between-language priming of picture naming should have been stronger when responding in the nondominant language. Similarly, with task-based difficulty effects on priming, we would have expected priming between picture naming and translation to be stronger when translation was the test task.

Some of the differences among conditions are also consistent with process-based difficulty but inconsistent with task-based difficulty explanations. First, in Experiment 2, picture naming in the nondominant language takes the same or less time than translation to the dominant language (with prime-phase mean response times of 1,124 ms and 1,169 ms, respectively, and second-phase control condition means of 1,293 and 1,315, respectively). However, picture naming in the nondominant language exhibited more than twice as much priming than did translation to the dominant language (230 ms and 96 ms, respectively). This effect is contradictory to the task-difficulty expectation, because tasks of the same difficulty level elicited very different magnitudes of priming. However, this result can be easily accommodated if difficulty is considered to be process based; the word-retrieval processes presumed to be primed in these conditions are more difficult when responding in the nondominant language. A second aspect of the data that would be difficult to explain with task-based difficulty is that the asymmetry in priming between translation to the nondominant language and translation to the dominant language (130 ms) is larger than the asymmetry in new-item response times for these tasks (53 ms). This aspect of the data can again be explained in terms of the relative difficulty of the word-retrieval processes being primed. Other asymmetries, such as the stronger priming of picture naming when the response language matches in Experiment 1 and the stronger priming of picture naming in both experiments when responding in the nondominant language can be accommodated under either difficulty explanation. These aspects of the data show that overall difficulty of the test task is not a reliable predictor of cross-task priming. However, all of the asymmetries and asymmetries in priming observed are consistent with process-based difficulty predictions.

A Simple Mathematical Model of Transfer-Appropriate Priming

Across the two experiments, eight priming effects were examined, each elicited by a different combination of study and test tasks. All of the priming effects were thought to be based on shared picture identification, shared word retrieval in the dominant language, shared word retrieval in the nondominant language, or some combination of these processes. The shared processes that were used to derive repetition-priming predictions for the two experiments are indicated in Table 3 for each of the eight combinations of study and test tasks. A set of explicit mathematical process models was derived to evaluate the contributions of each process to repetition priming. Different versions of the models were derived to include parameters that would allow for and measure (a) contributions of task difficulty, (b) influences of incidental activation of the nontarget language at encoding, (c) temporal overlap of identification and retrieval processes, and (d) nonindependence of identification and retrieval processes. (However, as explained in the following paragraphs, these additional parameters were not necessary, and tests of the models that include them are not covered.) The modeling technique was similar to one used by Theios and Amrhein (Amrhein, 1994; Theios & Amrhein, 1989) to model response times.

Testing of models began with the most restricted model, with the minimal set of parameters (the three process parameters). The other parameters were to be added one at a time and in combination to determine whether fit would improve substantially relative to the restricted model. Thus, in the first step, the only parameters were the parameters assigned to each of the three processes, which corresponded to their contributions to priming. The three parameters were estimated by using a least-squares procedure that minimized the sum of the squared discrepancies between the model and the observed priming magnitudes. (This procedure involves deriving the best solution for a set of eight linear equations involving three process variables, using 1 as the coefficient for each set of processes that is shared and 0 as the coefficient for each set not shared by the study–test task combination.) Table 3 shows the model predictions of priming, and the observed priming magnitudes are repeated for ease of comparison. The model had eight free data points and three parameters, leaving five degrees of freedom. The fit of the model was remarkable, with an average absolute discrepancy of only 2.7 ms, root-mean-square error = 3.0 ms, \(R^2 = .999\), ID = identification; L1 = dominant language; L2 = nondominant language.

<table>
<thead>
<tr>
<th>Prime Task</th>
<th>Test Task</th>
<th>Word retrieval</th>
<th>Priming (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naming L1</td>
<td>Naming L1</td>
<td>X X</td>
<td>218 221</td>
</tr>
<tr>
<td>Naming L2</td>
<td>Naming L1</td>
<td>X X</td>
<td>118 115</td>
</tr>
<tr>
<td>Naming L2</td>
<td>Naming L2</td>
<td>X X</td>
<td>344 341</td>
</tr>
<tr>
<td>Naming L1</td>
<td>Naming L2</td>
<td>X X</td>
<td>118 122</td>
</tr>
<tr>
<td>Translation L2-L1</td>
<td>Naming L1</td>
<td>X X</td>
<td>100 101</td>
</tr>
<tr>
<td>Translation L1-L2</td>
<td>Translation L2-L1</td>
<td>X X</td>
<td>100 96</td>
</tr>
<tr>
<td>Translation L1-L2</td>
<td>Naming L2</td>
<td>X X</td>
<td>226 230</td>
</tr>
<tr>
<td>Translation L1-L2</td>
<td>Translation L1-L2</td>
<td>X X</td>
<td>226 227</td>
</tr>
</tbody>
</table>

Note. X indicates that the process is shared by the prime and test tasks. Parameter estimates were 118 ms for picture identification, 100 ms for dominant-language word retrieval, and 226 ms for nondominant-language word retrieval. Average absolute discrepancy = 2.7 ms, root-mean-square error = 3.0 ms, \(R^2 = .999\), ID = identification; L1 = dominant language; L2 = nondominant language.
in the dominant language, and word retrieval in the nondominant language were 118 ms, 100 ms, and 226 ms, respectively. The model shows that within the context of the data presented here, we need only posit three sets of processes—picture identification, word retrieval in the dominant language, and word retrieval in the nondominant language—and these sets of processes alone can account for the pattern of repetition priming observed. As tested, the model is maximally restricted with regard to the theory. The model contains no special difficulty parameters. Because process difficulty effects arise naturally out of the processes shared by different pairs of tasks, incorporating process difficulty does not require adding parameters. Process difficulty arises naturally by not forcing the parameters for the three different processes to be equal to each other.

Adding task-based difficulty parameters would not substantially improve the fit of the model. The model results support the principle that shared processes are the primary basis of priming and the idea that the influences of difficulty on priming occur at the process level rather than at the task level. There is also no evidence that incidental activation of the nontarget language at study influences repetition priming at the delay tested. Perhaps the influence of such activation would be evident with a shorter delay from study to test. In this restricted model, picture-identification and word-retrieval processes were treated as independent and sequential. As explained, the model could be expanded to include interaction or overlap in these two sets of processes by adding parameters. However, because the fit was nearly perfect with the independent model, adding parameters of any type would not substantially improve the fit of the model to the present data set. Of course, we cannot completely rule out the possibility that these other factors had influences on repetition priming that were collinear to the process parameters or canceled each other out. However, the more parsimonious explanation is that these factors did not influence repetition priming in the present set of experiments.

**Implications for Bilingual Language Processing**

Although the main purpose of this series of experiments was to examine bases of repetition priming, the findings also have implications for theories of bilingual-language processing. The nature of conceptual and lexical access in bilinguals has been a question of interest to cognitive psychologists for several decades. Past research shows clearly that, at least for concrete nouns such as those used in the present study, pairs of translation equivalents have shared conceptual representations (for extensive reviews of this evidence, see Francis, 1999, in press). Current research in the area focuses more on issues of how words and concepts are accessed for comprehension and production.

As explained in the introduction, there is strong experimental evidence in the literature and agreement among researchers that picture naming in fluent bilinguals is concept mediated in both the dominant and nondominant language. Experiment 2 replicated one pattern previously used as evidence for concept-mediated naming and translation when responding in the nondominant language. Translation to the nondominant language took a little longer (about 70 ms, depending on whether prime-phase or test-phase new items were compared) than naming pictures in the nondominant language (replicating effects observed by Chen, 1990; Chen & Leung, 1989; Potter et al., 1984). (For detailed explanations of the logic behind the use of response time patterns as evidence for concept and word mediation, see Potter et al., 1984; Snodgrass, 1993.)

Arguably the strongest evidence in the literature regarding the concept-mediated or word-mediated nature of translation comes from the Sholl et al. (1995) study of repetition priming in late English–Spanish bilinguals living in a primarily English-speaking environment. Picture naming in the nondominant language primed translation to the nondominant language, indicating that translation to the nondominant language was concept mediated. In contrast, picture naming in the dominant language did not prime translation to the dominant language (with the nonsignificant effect being only 13 ms), indicating that translation to the dominant language was word mediated. Experiment 2 of the present study included replications of these critical conditions, but with a sample of relatively early Spanish–English bilinguals living in a bilingual immersion context. These bilinguals exhibited substantial priming from picture naming to translation in both the nondominant language (227 ms) and the dominant language (96 ms), indicating that translation was concept mediated in both directions.

As indicated, priming from picture naming to translation was about twice as strong when responding in the nondominant language. Perhaps the reason is not simply that word-retrieval processes are more difficult in the nondominant language, as we have concluded, but that translation to the dominant language is word mediated about half the time and concept mediated about half the time. This issue can only be addressed by comparing the results of both experiments. Recall that in Experiment 1, picture naming in the dominant language exhibited more priming (by 106 ms) when the language matched from study to test, presumably because of additional shared word-retrieval processes. In the case of priming between translation and picture naming in the dominant language, if the word-retrieval process were shared only about half of the time, then the priming should have been only about half that magnitude, about 50 ms, but the mean priming effects obtained were 96 ms and 101 ms. This issue is more parsimoniously tested through the mathematical process model explained in the previous section. If translation were word mediated about half of the time, then the model would not fit because the priming between picture naming and translation would be much lower than the difference between within-language and between-language priming of picture naming.

As explained earlier, recent cognitive research on bilingual lexical processing has raised the questions of whether the nontarget language is incidentally activated during picture naming and how such activation might impact performance (Colomé, 2001; Costa et al., 1999, 2000; Hermans et al., 1998). The pattern of priming effects obtained in the present study indicate that either (a) such activation did not occur or (b) such activation does not impact picture-naming performance after a delay filled with several intervening trials. If the activation had occurred and had a continuing impact, it would have increased priming in the between-language conditions of Experiment 1, making symmetric priming across languages unlikely. This conclusion is more clearly illustrated by using the mathematical model, which would not have fit if incidental activation of the nontarget language had an enduring effect. This is because priming in the between-language picture-naming conditions would have been based not only on shared picture-identification processes but also on shared word-retrieval pro-
cesses. As a result, the sum of priming of picture naming between languages and priming of picture naming from prior translation would have been greater than, rather than equivalent to, the priming of picture naming within a language. There was no indication in either language of extra priming from incidental activation of the nontarget language. In a separate series of experiments, Francis and colleagues (Francis, 1998; Francis et al., 2002) have obtained stronger evidence of the independence of the contributions of picture-identification processes and word-retrieval processes to priming in picture naming. Within each of the two experiments that used the same tasks as in the present study, the sum of facilitation for the two tasks was equivalent to the facilitation observed when both tasks were performed on separate trials (Francis, 1998; Francis et al., 2002).

The conclusion that implicit activation of the nontarget language does not impact processing of an item after several intervening trials is consistent with findings from related tasks. The activation of nontarget translation equivalents might be compared with the activation of semantic competitors during naming or with the activation of unattended items presented at study in single-language studies. Prior production of a semantic competitor in response to a definition has been shown to inhibit picture naming at a lag of only a few seconds, but this effect disappeared after a delay of several minutes (Wheelon & Monsell, 1994). In a picture-naming task in which only one of two presented pictures was named, ignored pictures exhibited facilitation in naming immediately but not after several intervening trials (Stankiewicz et al., 1998). The continued impact of nontarget language activation in bilingual picture naming has not yet been assessed empirically. In a related paradigm, producing words in response to definitions, which may likewise elicit activation of translation equivalents in the nontarget language, primes later picture naming in the target language but not in the nontarget language (Lee & Williams, 2001; Monsell et al., 1992). Also, lexical decisions on words were facilitated by prior presentation of the translation equivalent when there were no intervening items between prime and target, but no facilitation was observed in experiments with a delay of several trials (see Francis, 1999, for a detailed review of these studies). In the present study, it appears that only word-retrieval processes in the language selected for production in an encoding-phase block impacted later processing. The idea that even if activation spreads to words in both languages only words in the target language are selected (retrieved) is consistent with Costa et al. (1999, 2000), and selection may be necessary for a long-term impact on processing.

Conclusions

The patterns of symmetric priming between tasks thought to share a process indicate that repetition priming is influenced by the difficulty of common processes required by the encoding and test tasks but not by the overall difficulty level of the test task. A simple mathematical model that used shared processes as the sole basis of priming was used to demonstrate that the pattern of priming across the conditions of both experiments could be explained with only three process parameters. It was not necessary to include parameters for task difficulty, interactions, or overlap between identification and retrieval processes. We have examined the independence of picture-identification and word-retrieval processes more directly in a separate series of experiments (Francis, 1998; Francis et al., 2002).

The patterns of new-item response times and priming effects also have implications for bilingual lexical processing. The patterns of priming, in particular the substantial priming between picture naming and translation tasks in Experiment 2 and the fit of the mathematical process model, indicate that picture naming and translation in both languages are concept mediated in fluent bilinguals. Although recent findings suggest that bilingual picture naming elicits incidental activation of the nontarget language, such activation does not appear to influence processing after several intervening items, as indicated by the symmetric between-language priming of picture naming in Experiment 1 and the fit of the process model. Cognitive research on bilingual language processing has been criticized in the past for having more theory than data (e.g., Snodgrass, 1993), and 10 years later, this problem is only slowly being resolved. This data shortfall arises in part from difficulties that bilingual researchers have in recruiting participants in regions where bilingual populations are not available and from inherent complexities in bilingual materials construction, design, and interpretation. It is unfortunate that in many mainstream memory laboratories in the United States, fluency in a language other than English is considered an undesirable participant characteristic. Bilingual experiments can be used not only for advancing theory on bilingualism per se but also to facilitate testing general hypotheses about memory that are otherwise difficult if not impossible to isolate.

References


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