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Decomposition of Repetition Priming Processes in Word Translation

Wendy S. Francis,
University of Texas at El Paso

Gabriela Durán,
University of Texas at El Paso

Beatriz K. Augustini,
University of Texas at El Paso

Genoveva Luévano,
University of Texas at El Paso

José C. Arzate, and
University of Texas at El Paso

Silvia P. Sáenz
University of Texas at El Paso

Abstract

Translation in fluent bilinguals requires comprehension of a stimulus word and subsequent production, or retrieval and articulation, of the response word. Four repetition-priming experiments with Spanish-English bilinguals (N = 274) decomposed these processes using selective facilitation to evaluate their unique priming contributions and factorial combination to evaluate the degree of process overlap or dependence. In Experiment 1, symmetric priming between semantic classification and translation tasks indicated that bilinguals do not covertly translate words during semantic classification. In Experiments 2 and 3, semantic classification of words and word-cued picture drawing facilitated word comprehension processes of translation, and picture naming facilitated word production processes. These effects were independent, consistent with a sequential model and with the conclusion that neither semantic classification nor word-cued picture drawing elicits covert translation. Experiment 4 showed that two tasks involving word retrieval processes, written word translation and picture naming, had subadditive effects on later translation. Incomplete transfer from written translation to spoken translation indicated that preparation for articulation also benefited from repetition in the less fluent language.

Address correspondence to Wendy S. Francis, Department of Psychology, University of Texas at El Paso, 500 West University Avenue, El Paso, Texas 79968, wfrancis@utep.edu.

Author Note

Wendy S. Francis, Gabriela Durán, Beatriz K. Augustini, Genoveva Luévano, José Arzate, and Silvia P. Sáenz, Department of Psychology, University of Texas at El Paso.

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Through a series of bilingual repetition priming experiments, the present study evaluates whether a discrete sequential model is adequate to account for changes in word-translation performance following the practice of its components. A bilingual word-translation task is employed because it involves both word-comprehension and word-production components, the two components whose processes, when practiced, give rise to proficiency in vocabulary access. The experiments combine factorially encoding tasks meant to selectively facilitate the component processes of translation, thus allowing estimation of the unique contribution of each component and their interaction or independence. At the same time, we are able to examine the nature of repetition priming, including the conditions of transfer, what processes contributed, what exactly was learned, and why response times (RTs) decreased with practice. We assess in a unique way whether semantic classification, word-cued picture drawing, and picture naming (all used as encoding tasks) involve access to non-target language representations. Finally, we examine effects of language proficiency and experimental practice on word comprehension and production.

Repetition Priming and Implicit Memory

Repetition priming is an item-specific change in RT, accuracy, bias, or attribution in task performance based on previous experience. Across several tasks, including picture naming, lexical decision, semantic decision, verb generation, and word translation, the measure of repetition priming is the reduction in RT for repeated items relative to new items at test. Long-term repetition priming reflects a non-hippocampal form of implicit learning, as indicated by its preservation in global amnesia. Amnesic patients exhibited intact speeding of responses to repeated items for lexical decision (Smith & Oscar-Berman, 1990), category verification (Levy, Stark, & Squire, 2004), picture naming (e.g., Cave & Squire, 1992), and verb generation (Seger, Rabin, Zarella, & Gabrieli, 1997). Such results show that RT improvement in word comprehension and production with practice does not require support from explicit memory. The long-term impact of this learning is evident in that priming for picture naming lasts across delays of several days or weeks (e.g., Cave, 1997; Mitchell & Brown, 1988). The long-term effects of repetition priming indicate that it reflects sustained learning, rather than a short-term fluctuation in activation levels.

Dissociations among implicit memory tasks have revealed that implicit memory has multiple cognitive and neural bases (Gabrieli, 1998; Schacter & Buckner, 1998). Multiple mechanisms of facilitation can also operate within a single repetition-priming paradigm. For example, repetition-priming effects in picture naming based on identification and production components were shown to have different forgetting rates (Francis & Sáenz, 2007) and linearly additive contributions (Francis, Corral, Jones, & Sáenz, 2008), consistent with a sequential model with independent identification and production processes. In the present study, we extended this approach to bilingual word translation, which also exhibits repetition priming at retention intervals ranging from several minutes (Francis & Gallard, 2005;

Francis & Sáenz, 2007; Francis, Tokowicz, & Kroll, 2010) to one week (Francis & Sáenz, 2007).

The experiments to follow used an additive factors approach to test whether a sequential model with independent processing components for comprehension and production adequately explains repetition priming in word translation, or whether such a model must be rejected in favor of one that allows for overlap or dependence. Predictions were derived from an explicit model based on the principle of *transfer-appropriate processing*, the idea that the degree of transfer from study to test depends on the degree to which the cognitive processes involved in the encoding and test tasks overlap (Morris, Bransford, & Franks, 1977; Roediger & Blaxton, 1987). In the explicit model, the practice of processes shared by encoding and test tasks was assumed to be the sole causal basis of repetition priming (Francis et al., 2003; Francis et al., 2008; Francis & Sáenz, 2007). The present series of experiments decomposed implicit memory processes within a single memory paradigm and tested the model. These tests were implemented with a focus on the involvement of word comprehension and production processes in repetition priming for bilingual word translation. This strategy requires an analysis of the processes involved in translation.

Processes in Bilingual Word Translation

Evidence that translation equivalents for concrete nouns access the same conceptual representation is well established in the cognitive bilingual literature (for reviews see de Groot, 1992a; Francis, 1999, 2005). Translation tasks that involve access to this common concept are said to be *concept mediated*. There is consensus in the literature that spoken word translation in both directions is concept mediated in fluent early bilinguals (e.g., De Groot, Dannenburg, & Van Hell, 1994; De Groot & Poot, 1997; Duyck & Brysbaert, 2004; Francis, Augustini, & Sáenz, 2003; Francis & Gallard, 2005; La Heij, Hooglander, Kerling, & van der Velden, 1996; Miller & Kroll, 2002; Potter, So, Von Eckhardt, & Feldman, 1984). Concept-mediated spoken word translation can be decomposed into two sets of processes. The first, *word comprehension*, includes the processes that occur between presentation of the stimulus and access to the concept. The second, *word production*, includes the processes that occur after the concept is accessed and lead to overt articulation of the word.

Research on word translation has focused on the processing routes used by different types of bilinguals and factors that affect the speed of translation, and model development has focused on how to account for these factors. This research has not yet provided a fine-grained analysis, and the models have not yet dealt with issues of independence or interdependence of the comprehension and production stages of processing. However, many models have been developed to try to explain word comprehension or production processes in monolingual or bilingual individuals.

Models of word comprehension and production have outlined sets of processes that are required and processes that occur incidentally (i.e., unintentionally) as words are comprehended and produced. Comprehension of written words requires perceptual processes that lead to formation of a graphemic (orthographic) word form, which is then matched against representations in long-term memory to access the corresponding lemma (syntactic word form) and meaning (e.g., Dijkstra & Van Heuven, 2002; Green, 1998).

Graphemic word forms, lemmas, and meanings of orthographically related words may be incidentally coactivated. The corresponding phonological form may also be incidentally activated. Models of word production typically include the processes of accessing a lemma, accessing the corresponding phonological word form (lexeme), selecting and sequencing the phonemes to be articulated, and overt articulation of the response (e.g., Dell & O'Seaghdha, 1991; Levelt et al., 1999). Alternative candidate lexemes and phonemes may be activated incidentally, and the graphemic word form may also be accessed. (In bilingual models of comprehension and production, there is also the possibility that the translation equivalent or other words in another language are also activated, and this issue is addressed in the *Language Nonselective Access* section.)

Models of comprehension and production vary in terms of whether they are discrete or cascaded, whether they are strictly sequential (feed forward) or interactive (with feedback loops), and whether they involve inhibitory processes. However, none have addressed the question of whether comprehension processes must be complete before production processes begin in bilingual word translation. If the comprehension and production processes of translation are independent for words that do not have "special" relationships (e.g., homographs, homonyms, cognates), then simply combining compatible comprehension and production models (or adapting a combined comprehension/production model) would be a possible approach for further detailing a model of concept-mediated translation. Although our previous research showed that object identification and word production components of picture naming were independent (Francis et al., 2008), there are more reasons to suspect interactivity with comprehension and production in translation, because in translation both sets of processes are language based.

Repetition Priming in Translation

Any of the processes required for translation that are not over-learned are potential loci for facilitation or learning when translation is repeated. Previous research suggests that both comprehension and production processes of translation are susceptible to long-term repetition priming. The most direct evidence that word comprehension processes in translation exhibit repetition priming when those processes are practiced at encoding was obtained in a trilingual study in which English-Spanish translation primed English-French translation (111 ms), and French-Spanish translation primed French-English translation (173 ms; Francis & Gallard, 2005). Experiments 1, 2, and 3 of the present study attempt to provide direct evidence for learning in the word comprehension component in bilinguals.

Production processes in translation also exhibit repetition priming, as evidenced by two studies in which picture naming primed later translation when the response language stayed the same (Francis et al., 2003; Sholl et al., 1995). Also, in our trilingual study, Spanish-French translation primed English-French translation, and Spanish-English translation primed French-English translation (Francis & Gallard, 2005). We reasoned that all of these effects were based primarily on the process of retrieving the appropriate phonological word form based on the concept rather than articulation, because in single-language studies, repetition of articulation alone elicited little if any facilitation (Durso & Johnson, 1979; Durso & O'Sullivan, 1983; Wheeldon & Monsell, 1992) with the average nonsignificant effect being about 10 ms, and priming for overt production was not reduced when responses at encoding were made covertly (Brown et al., 1991). However, this conclusion was not tested directly, and the previous studies with monolingual participants do not rule out the possibility that articulation could be facilitated in a bilingual's less fluent language; this possibility was tested in Experiment 4.

Language Nonselective Access

Recent research on bilingual lexical access has focused on the extent to which the unintended (nontarget) language is accessed during comprehension or production of the other language. Several recent results suggest that lexical access in bilingual comprehension and production is *nonselective* with respect to language even in single-language contexts, particularly when the task is performed with isolated words in L2. In comprehension, a number of mediated priming and interference effects have been employed to show that even a noncognate translation equivalent may be incidentally activated during word reading. Specifically, activation spread to words related in form to the noncognate translation equivalent (e.g., alone-solo-sold) and the translation equivalents of form-related words in the nontarget language (e.g., car-cara-face; Schwartz & Fontes, 2008). In production, this question has been addressed using picture-naming paradigms. Incidental activation of the nontarget language appears to have consequences for immediate processing of both the target and nontarget language, (Costa, Miozzo, & Caramazza, 1999; Colomé, 2001; Hermans, Bongaerts, de Bot, & Schreuder, 1998). However, no study has demonstrated that this nonselectivity affects processing after more than a few seconds have elapsed. The present research tested whether there were long-term processing consequences.

It is important to make a distinction here between these sorts of "incidental" activation, when a representation is activated but is not the focus of the task, and intentional covert access, in which the person makes efforts to access the representation but does not execute an overt response. For example, when a person names a picture of a dog in English, the Spanish equivalent perro may also come to mind unintentionally as a result of incidental activation. It is also possible for a person to intentionally retrieve the Spanish name in addition to the English name but not report it, showing intentional covert access. The present research also tested whether participants intentionally accessed the non-target language at encoding.

Transfer-Appropriate Processing Logic and Additive Factors Approach

In the present study, predictions about repetition priming were derived from a specific interpretation of transfer appropriate processing in which common processes between encoding and test tasks are *the sole causal basis* of facilitation. Processes were defined in terms of the operations completed, rather than levels of representation activated. Repetition of these processes was assumed to strengthen the links or connectivity *between* mental representations, rather than increasing activation in the representations themselves. This version of transfer appropriate processing is similar to those used by previous researchers to reason about repetition priming (Monsell et al., 1992; Sholl et al., 1995, Wheeldon & Monsell, 1992). However, we took this logic a few steps further (as in Francis et al., 2008; Francis & Sáenz, 2007) by making the bases for deriving predictions more explicit.

Tasks were defined in terms of their component processes. A process was defined by its start and end points and the path taken between them, all of which had to match for two processes to be considered equivalent. However, only the path was assumed to take time and was used to predict priming. Prior practice of processes *necessary* to complete a test task will elicit facilitation (Franks et al., 2000), unless the practiced process or processes are overlearned. This repetition priming manifests itself as a decrease in RT. Practice at encoding of a subset of processes necessary for completion of the test task exerts a selective facilitating influence on those processes upon repetition of the item, resulting in a corresponding decrease in completion time.

Encoding manipulations meant to selectively facilitate word comprehension or word production were combined factorially, in accordance with the *additive factors* approach. According to this approach, if the application of two or more selective influences elicits an effect equivalent in magnitude to the sum of the effects associated with each selective influence applied separately, then the processes can be regarded as sequential and independent (e.g., Townsend & Schweickert, 1989). With RT as the dependent variable, this pattern is equivalent to linear additivity, or the absence of an interaction. In contrast, if the application of two or more selective influences results in subadditive facilitation relative to the sum of effects of separate applications, then the processes either overlap in time or are otherwise nonindependent.

This logic raises the question of whether it is possible to obtain subadditive priming effects when two encoding tasks require the completion of overlapping processes also necessary for the test task. Although no data are available on multiple repetitions of spoken translation, in picture naming, the effects of multiple identical practice trials were subadditive (e.g., Bartram, 1974; Brown, Jones, & Mitchell, 1996; Gollan, Montoya, Fennema-Notestine, & Morris, 2005). Translation verification also exhibited subadditive effects across successive trials (Izura & Ellis, 2004). That is, the effect of having two practice trials was less than two times the effect of a single practice trial, a pattern that simply reflects the diminishing benefit obtained from successive practice trials in a standard learning function. (In these four studies, it was also the case that multiple practice trials led to a stronger facilitation effect than a single practice trial.) Experiment 4 directly tested this assumption for partial repetition in spoken translation.

The Present Study

Across experiments, encoding tasks were chosen based on the processes they share with word translation. Each experiment in this study included a set of repetition conditions meant to selectively facilitate word comprehension, word production (retrieval and/or articulation), or a combination of these processes. Figure 1 illustrates the encoding tasks used and the processes they share with spoken word translation.

With respect to independence, in each experiment, the critical comparisons were those among the sum of the two individual priming effects, the priming effect in the combined condition, and the priming effect in the identical repetition condition. Figure 2 clarifies the predicted patterns of priming in these key conditions for three situations in which one task begins with the same stimulus as the test task and the other ends with the same response as the test task. First, in a perfect decomposition, the processes primed by the two encoding tasks do not overlap and together involve all processes in the test task. In this case, the combined condition effect will be equivalent to the sum of the two individual effects and to the identical repetition effect. A second possibility is that the processes primed by the two encoding tasks are sequential but do not account for all processes in the test task. In this situation, the combined condition effect will be equivalent to the sum of the individual conditions; however, it will fall short of the identical repetition effect. A third possibility is that the processes primed by the two encoding tasks overlap or have some processes in common. Here, a subadditive interaction is expected, such that priming in the combined condition falls short of the sum of priming effects in the individual conditions. To the extent that a second repetition of a process confers additional benefit, the combined condition effect will exceed the identical repetition effect.

Experiment 1 examined whether common word-comprehension processes were sufficient to elicit repetition priming between semantic classification and translation tasks and whether semantic classification in L2 would elicit covert translation. In Experiments 2 and 3, additive factors logic was used to decompose processes contributing to repetition priming in word translation. In each case, one encoding task was meant to facilitate word comprehension and one was meant to facilitate word production processes, and these manipulations were combined factorially. In Experiment 4, tasks meant to facilitate overlapping sets of processes were combined factorially in order to show that a subadditive pattern can be obtained under these conditions and to evaluate whether a second process repetition elicits additional facilitation. The tasks chosen also made it possible to evaluate whether articulation benefits from repetition and contributes to repetition priming in word translation.

Experiment 1

Semantic classification of words requires conceptual access or comprehension of the words and therefore seemed an appropriate task to facilitate the word comprehension processes of word translation. Because both tasks require word comprehension, performance of either task should benefit from prior practice on the other task with the same items. As explained in the introduction, word translation benefits from repetition. Semantic classification of words has exhibited repetition priming for a variety of semantic decision types, including category membership (verification), concrete/abstract, natural/manufactured, animacy, size, and likeability (Durso & Johnson, 1979; Franks et al., 2000; Thompson-Schill & Gabrieli, 1999; Vaidya & Gabrieli, 2000; Vriezen, Moscovitch, & Bellos, 1995; Xiong, Franks, & Logan, 2003; Zeelenberg & Pecher, 2003). Semantic classification was also primed by prior semantic classification on a different basis, although these effects were weaker and less consistent (Franks et al., 2000; Thompson-Schill & Gabrieli, 1999; Xiong et al., 2003). These findings of priming across decision types suggest that common comprehension processes take place for tasks that involve word comprehension but require different responses. We therefore expected that translation would prime later semantic classification, and semantic classification would prime later translation. This expectation is analogous to the findings that picture naming primed semantic classification of pictures, and semantic classification of pictures primed picture naming (Carroll, Byrne, & Kirsner, 1985; Francis et al., 2008).

However, the degree of facilitation will also depend on whether comprehension processes are the only processes shared. Clearly, semantic classification of words is performed without translation in monolinguals. In fluent bilinguals, it is clear that words are not translated prior to making a semantic classification, because semantic classification RTs in both L1 and L2 are much faster than word translation RTs (Potter et al., 1984). However, it is unknown whether bilinguals covertly translate the words anyway (either in parallel with or subsequent to the classification response), which would involve word retrieval processes. If semantic classification elicited word retrieval, then it would be a bad candidate task to selectively facilitate word comprehension processes. Similarly, if semantic classification led to incidental activation of the translation equivalent and that activation had a lasting effect, it would be a bad candidate for selective facilitation of word comprehension. Such covert translation or long-lasting effects of activation would be expected to lead to greater priming from semantic classification to word translation than from word translation to semantic classification.

Across studies, within-task repetition-priming effects tend to be smaller for semantic classification than for translation, even for bilingual semantic classification (Francis & Goldmann, 2010; Zeelenberg & Pecher, 2003). However, the between-task facilitation effects have not been tested previously or compared. Experiment 1 included these conditions. Intentional covert production has been shown to facilitate later overt production as much as an identical overt naming production in a picture-naming task (Brown et al, 1991). Therefore, if semantic classification elicited covert translation, it was expected to facilitate translation more than translation facilitates classification. In contrast, if word comprehension processes were the only shared processes, then between-task priming was expected to be symmetric. That is, the degree of between-task facilitation either way should be equivalent. This between-task comprehension priming was expected to be greater when the comprehension processes were more difficult, as in L2.

For this experiment, in order to concentrate power in the between-task conditions, four between-task repetition conditions (and no identical repetition conditions) were incorporated for two final tasks and two languages. For example, in the English classification-translation condition, a participant might classify *tree* at encoding as natural and translate *tree* to *árbol* at test. In the Spanish translation-classification condition, they might translate *silla* to *chair* at encoding and classify *silla* as manufactured at test. The stimulus language for a given item was always held constant from study to test. Each task/language combination also had a set of control items that were not presented at encoding.

Method

Participants.—Participants were 64 self-identified Spanish-English bilinguals (42 women, 22 men) ranging in age from 17 to 32 (*Mdn* = 19). All but 1 reported Hispanic ethnicity. According to self-reports, 54 students had learned Spanish first, 5 had learned English first, and 4 had learned both Spanish and English simultaneously from early childhood (1 did not respond). The median age of first exposure to the second language was 6 years. According to self-ratings of relative proficiency, 43 were classified as English dominant and 21 were classified as Spanish dominant. They reported that over the last month, they had used

English 48%, Spanish 34%, and a mixture 18% of the time; this corresponded to speaking the dominant language 50% of the time and the nondominant language 32% of the time. Eleven other students completed the protocol but were excluded and replaced because of low accuracy.

Apparatus.—Stimuli were presented on the monitor of a Macintosh G4 computer, and the sequence and timing of presentation were programmed using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Vocal naming RTs were collected by means of a PsyScope button box (New Micros, Dallas, TX) with a high-impedance microphone attached.

Design.—Experiment 1 had a 2 (final task) × 2 (final stimulus language) × 2 (repeated or new) within-subjects factorial design. The final task was either word classification or translation, with the final stimulus language either English or Spanish. Half of the items in the final-phase classification and translation blocks were those previously translated or classified (always the opposite task), and half were new items. Corresponding pairs of classification and translation items always had the same stimulus language.

Materials.—Experimental stimuli were 344 concrete nouns, all names of objects that have been used as pictures in picture-naming experiments. The mean letter lengths were 5.7 in English and 6.3 in Spanish, with a median English frequency of 13 per million (Kuçera & Francis, 1967). 136 of the words were names of objects that occur naturally and 208 were the names of manufactured objects. The experimental stimuli were randomly assigned to 8 sets of 43, keeping the proportions of natural and manufactured items constant across sets. These 8 sets were rotated among the 8 experimental conditions across subjects using a Latin square to control for specific-item effects. Encoding phase trial blocks each contained one item set; items were presented in random order with the restriction of no more than 3 consecutive natural or manufactured trials. Test phase trial blocks each contained two item sets (one old and one new); these items were presented in random sequence with no more than 3 natural or manufactured items and no more than three items from either list appearing consecutively.

Procedure.—Participants were tested individually in sessions lasting approximately 45 minutes. Before beginning the experiment, participants were given practice using the voice relay microphone with a number-naming task. Before each block of experimental trials, instructions were given in the language in which stimuli were to be presented. All participants completed 4 encoding-phase blocks of 43 trials each and 4 test-phase blocks of 86 trials each. After completion of the test phase, participants completed two additional blocks of 43 translation trials that contained the same stimuli as the new-item word classification sets in the test phase. These control blocks served as a means to identify items not known in both languages. The orders of tasks and languages were counterbalanced across participants, with the stimulus language order held consistent across encoding, test, and control phases of the experiment.

On each trial, the stimulus remained on the screen until a response was registered, and the next stimulus appeared after 1250 ms. For the classification task, participants were to decide whether each word was natural or manufactured and press the corresponding button. Button press RTs for classification trials were recorded using the button box. On translation trials, vocal RTs were recorded using the microphone and button box, and the experimenter noted unexpected responses and timing errors. Upon completion of the response-time tasks, participants completed a language background questionnaire and were debriefed.

Results—Because analysis focused on RTs in the test phase of the experiment, invalid test phase trials were removed before extracting the condition means for each participant. In the test phase 11.6% of trials were removed because of response errors, 0.9% were removed because of invalid timing (voice relay misfires), and 11.7% were removed as spoiled trials. Spoiled trials included those for which the corresponding encoding phase or control phase response was unacceptable (9.9%) or had invalid timing (1.0%), and translation trials for which the expected response was given as an error response to another item (0.8%). Items with RTs greater than 5000 ms, less than 200 ms, or more than 2 standard deviations from the condition mean were removed as outliers, which resulted in the exclusion of 4.6% of the trials. Thus, 71.2% were both correct and valid for the final analysis, on average about 31 trials per cell per participant.

Mean RTs and error rates for the encoding phase are given in Table 1. Mean RTs, priming effects, and error rates for the test phase are shown in Table 2 as a function of task and final stimulus language. New-item test-phase RTs were submitted to a 2 (Task) × 2 (Stimulus Language) repeated measures ANOVA. Translation took longer than classification, $F(1, 63) = 123.46$, $MSE = 75135$, $p < .001$, and responses took longer overall when words were presented in L2, $F(1, 63) = 16.25$, $MSE = 29021$, $p < .001$. However, the effect of response language was qualified by a significant interaction, $F(1, 63) = 8.754$, $MSE = 33721$, $p = .004$, showing that word classification took longer in L2, but translation did not exhibit a reliable asymmetry.

An analysis of new-item error rates showed that translation elicited more errors than classification, $F(1, 63) = 171.98$, $MSE = .00780$, $p < .001$. Overall, more errors were made when stimuli were presented in the dominant language, F(1, 63) = 13.65, MSE = .00325, p < .001, but this effect was qualified by a interaction of stimulus language and task, $F(1, 63) = 18.24$, $MSE = .00323$, $p < .001$. Classification error rates did not differ reliably for L1 ($M = 4.5\%$) and L2 ($M = 4.9\%$). Translation error rates were higher when stimuli were presented in L1 ($M = 22.1\%$) than when they were presented in L2 ($M = 16.4\%$), $t(63) = 4.406$, $p < .001$, presumably because of the greater difficulty in retrieval and production of L2 responses.

Repetition priming scores were obtained by subtracting the mean RT for repeated items from the mean RT for new items in the same task and language. Repetition priming was substantial and statistically reliable in all conditions (ps < .05), except for the L1 classification-translation condition, $t(63) = 1.675$, p = .0989. Priming scores were submitted to a 2 (Task) × 2 (Stimulus Language) repeated measures ANOVA. The main effect of test task did not approach significance, $F < 1$. The numeric priming advantage for L2 stimuli was not statistically significant, $F(1, 63) = 1.784$, $MSE = 34539$, $p = .187$. The interaction of test task and stimulus language did not approach statistical significance, $F < 1$. To see whether error rates were affected by prior comprehension exposure, new-item and repeated-item error rates were compared in each condition. However, the only condition in which the benefit of previous exposure approached significance was the L2 classification-translation condition, $t(63) = 1.995$, $p = .050$.

Discussion

Translation took over 300 ms longer than word classification for new items, which indicates that participants did not translate the words before semantically classifying them. Translation was facilitated by prior semantic classification of words, and semantic classification of words was facilitated by prior translation. Despite the fact that translation took much longer than semantic classification, it did not exhibit stronger between-task priming. Therefore, it can be concluded that semantic classification of words at encoding did not elicit covert translation, and that semantic classification will be an appropriate task to prime the word comprehension processes of translation in Experiment 2.

The magnitudes of the between-task priming effects were smaller than what was expected based on estimates from previous studies involving translation priming. This shortfall left open the question of whether these cross-task facilitation effects fail to account for all of the word comprehension processes that would be facilitated with identical repetitions. For example, it could be the case that the word comprehension processes were not fully primed or that the processes of word classification and translation diverge before the concept is accessed. Because the stimulus set and the bilingual participants were similar to those of our previous studies, it seemed unlikely that the shortfall was an artifact of item or participant properties that would make them less prone to facilitation. To determine whether all comprehension processes were accounted for, it was necessary to combine the word classification condition with a task meant to facilitate word production processes and an identical repetition condition to examine whether all processes were accounted for. Another remaining question was whether the facilitation observed for tasks with shared word comprehension processes would be independent of facilitation elicited by repeated word production processes. These questions were addressed in Experiment 2.

Experiment 2

In Experiment 2, manipulations meant to facilitate word comprehension and word production components of translation were combined factorially to assess their independence. As in Experiment 1, the encoding task meant to facilitate word comprehension in translation was semantic classification of words. The encoding task meant to facilitate word production was naming a picture in the same language as the later translation response (e.g., naming a picture of an apple in English at encoding and translating *manzana* to *apple* at test). Previous research has provided strong evidence that picture naming is *concept mediated* in monolinguals (Durso & Johnson, 1979; Potter & Faulconer, 1975; Smith & Magee, 1980) and fluent bilinguals (Chen & Leung, 1989; Francis et al., 2008; Potter et al., 1984). The processes required for picture naming can be decomposed into two sets. The first, *object identification*, includes perceptual processes that lead to identification of the object and retrieval of the concept. The second, *word production*, includes the processes that occur after the concept is accessed and lead to an overt verbal response. The word production processes of picture naming are the same as those used in word translation (Francis et al., 2003).

In order to assess the independence of the two manipulations meant to prime comprehension and production, a combined condition was incorporated, in which both encoding tasks were performed for the same concept on different trials. If the priming contributions of comprehension and production processes were independent, the combined condition priming effect was expected to equal the sum of the two individual priming effects. If they were dependent, a subadditive interaction was expected, such that the effect in the combined condition would fall short of the sum of the effects in the two individual conditions. An identical translation repetition condition was included to allow us to measure the effects of any processes not facilitated by the two encoding tasks and determine whether facilitation based on prior word classification would account for all comprehension processes necessary for translation.

Method

Participants.—90 self-identified Spanish-English bilinguals (28 men, 62 women) participated either for course research credit or for a payment of $5. All were undergraduate or graduate students of the University of Texas at El Paso. Participants ranged in age from 17 to 52 (*Mdn* = 20), and all but 2 reported Hispanic ethnicity. According to self ratings of relative proficiency, 59% of the students were classified as English dominant and 41% were classified as Spanish dominant. 93% of the students had learned Spanish first, 3% had learned English first, and 4% had learned both languages simultaneously from early childhood. The median age of second language acquisition was 6 years. They reported that over the last month, they had used English 47%, Spanish 39%, a mixture 13%, and other languages 1% of the time; this pattern corresponded to using the dominant language 54% and the nondominant language 32% of the time. An additional 24 participants completed the protocol but were excluded and replaced because of high error rates.

Design.—The experimental manipulations constituted a 5 (encoding condition) × 2 (final translation direction) within-subjects factorial design. The four critical encoding conditions were word classification (meant to prime word comprehension), picture naming (meant to prime word production), both tasks combined (meant to prime both processes), and neither task (not presented). These four conditions can be considered a 2 (stimulus word classified or not) × 2 (picture named or not) factorial design. The fifth encoding condition was identical translation.

Materials.—Experimental stimuli were pictures selected from the Snodgrass and Vanderwart (1980) set and their English and Spanish names. 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 shown to have low name agreement in English or Spanish were also avoided. The names used as stimuli and target responses were the most frequent English and Spanish responses to those pictures in a norming study conducted with students in the El Paso-Juárez region (Goggin, Estrada, &

Villareal, 1994), with average name agreement levels of 92% in English and 90% in Spanish. The mean letter lengths were 5.6 in English and 6.1 in Spanish, with a median English frequency of 14 per million (Kuçera & Francis, 1967). The 200 selected items were randomly assigned to 10 sets of 20 items. The sets were rotated through the 10 conditions across participants using a Latin square to control for specific item effects.

Procedure.—Participants were tested individually by a bilingual experimenter in sessions lasting about 45 minutes, using the same apparatus as in Experiment 1. After microphone practice, instructions were given for each block of trials in the appropriate response language for the task. In the encoding phase, there were 6 blocks of trials grouped by response language (English or Spanish), with language order counterbalanced. In each language, participants classified 40 words, named 40 pictures, and translated 20 words. (Twenty items were both classified and named on separate trials for the combined condition, which is why these tasks had more trials.) Within each block, 3 filler items preceded the experimental items, which were presented in a randomized sequence. The order of the tasks within each language was counterbalanced. The test phase consisted of an English translation block and a Spanish translation block, with each block consisting of 100 trials. Items from the various encoding conditions appeared in a block-randomized sequence, and the order of languages was counterbalanced. After the computerized portion of the study ended, participants completed a language background questionnaire.

Results

Four problematic items (2%) were removed for all participants. Data were trimmed in the same manner as for Experiment 1, resulting in the exclusion of 18.1% ($SD = 7.2\%$) of test phase trials as response errors, 0.9% as machine errors, 7.2% as spoiled trials, and 4.5% as outliers. (The breakdown of spoiled trials was 3.8% because of response errors at encoding, 0.8% because of timing errors at encoding, 0.8% because of inconsistent responses from encoding to test, and 1.8% because the expected response was given in error to an earlier item.) On average, 67% of test-phase trials were retained for analysis, or 13.5 items per cell per participant.

Mean encoding phase RTs and error rates are given in Table 1. Mean test phase translation RTs are shown in Table 3 as a function of encoding condition and final response language. New item RTs for L2-L1 and L1-L2 translation did not differ reliably, $t(89) = .532$, $p = .596$, although L2-L1 translation was more accurate, $t(89) = 3.036$, $p = .003$. Priming scores were obtained by subtracting RTs of the repeated conditions from RTs of the new item conditions, and are illustrated in Figure 3. Repeated items were translated faster than new items in all four encoding conditions (ps < .05).

RTs for the critical conditions were analyzed using a 2 (stimulus word classified or not) × 2 (picture named or not) × 2 (final translation direction) repeated measures ANOVA with RT as the dependent variable. Prior classification of the stimulus word facilitated later translation, $F(1, 89) = 21.847$, $MSE = 17913$, $p < .001$, indicating that word comprehension was facilitated. Prior picture naming in the final translation response language also facilitated later translation, $F(1, 89) = 117.038$, $MSE = 36714$, $p < .001$, indicating that word production was facilitated. However, these effects did not interact, $F < 1$. In other words, the combined effect of prior classification and prior picture naming (201 ms) did not differ reliably from the sum of the individual effects (50 ms + 158 ms = 208 ms). Although the effect of prior word classification did not differ across languages, $F < 1$, the effect of prior picture naming was stronger when responding in L2, $F(1, 89) = 7.077$, $MSE = 35857$, $p = .009$. The three-way interaction was not significant, $F < 1$.

In identical repetition conditions, priming did not differ reliably across the two translation directions, $t(89) = 1.53$, $p = .13$. A comparison of priming in the identical translation (302 ms) and combined conditions (201 ms) shows that about 100 ms of the identical priming effect was left unaccounted for when the partial priming tasks were combined, which was a significant shortfall, $F(1, 89) = 15.292$, $MSE = 51381$, $p < .001$.

Test phase error rates also varied as a function of the language and encoding conditions. For both languages, error rates for repeated items were significantly reduced relative to new items in conditions that required producing the response word (naming, combined, and translation conditions, ps < .05), but not in the classification conditions, which required only comprehending the stimulus word.

Discussion

Experiment 2 did show selective facilitation of word comprehension and production processes, in that the word classification and picture naming tasks had independent effects on priming. Although linearly additive, these two effects together fell about 100 ms short of the full priming effect observed with identical repetition of the translation task. This shortfall indicates that a subset of processes necessary for translation was not covered by either the word-classification or the picture-naming task.

This effect falls short of the priming obtained from translation to a neutral third language (Francis & Gallard, 2005), thus paralleling the finding that semantic classification of pictures primed picture naming less than did picture naming in another language (Francis et al., 2008). In both cases, the most obvious explanation is that semantic classification does not require the precise level of conceptual access achieved in translation or picture naming. This may be because semantic classification only requires access to the superordinate level concept associated with the stimulus, whereas translation requires access to the basic level concept. Another possibility in the case of semantic classification of words is that associative information can be accessed directly from the lemma. Experiment 3 incorporated an encoding task that was meant to engage more precise word comprehension processes than those required for semantic classification.

Experiment 3

Experiment 3 had the same structure as Experiment 2 but replaced the word-classification task with a word-cued picture-drawing task that was intended to prime word comprehension processes. For this task, a word appeared on the computer screen, and the participant was asked to draw a quick sketch of the object, taking no more than a few seconds per object. Examples of sketches produced are shown in Figure 4. This task was assumed to require precise access to the concept as well as access to a structural description for planning the sketch, as suggested by previous research (Amrhein & Sanchez, 1997). Words were presented for drawing in the same language that they were to be presented later for translation. For example, if *bird* were presented for drawing at encoding, then *bird* would be translated to *pájaro* at test. As in Experiment 2, the task meant to prime word production was picture naming in the language targeted for later translation responses. If the reason for the shortfall in word comprehension priming in Experiment 2 was because the conceptual access in semantic classification of words was not precise, then the picture-drawing task was expected to close the gap.

Incorporation of the word-cued picture-drawing task was also meant to make this experiment directly analogous to our previous trilingual translation priming experiment in which no shortfall was observed (Francis & Gallard, 2005). In both cases, the stimulus word was "translated" to a neutral 3rd form (here a drawing, rather than a 3rd language word), and the response word was produced based on "translation" from a neutral 3rd form (here a picture, rather than a 3rd language word). Based on this logic, an analogous pattern of results was expected, with the partial repetitions yielding substantial priming effects that sum approximately to the effect obtained with identical repetition.

One concern with the word-cued drawing task was the possibility that in bilinguals, word-cued picture drawing could elicit covert translation of the translation equivalent of the stimulus word, particularly if the cue was given in L2. The design of Experiment 3 made it possible to test whether covert translation occurred. Covert translation would lead to facilitation in word production at test, which would overlap with the word production processes facilitated by picture naming. In this case, the sum of priming effects elicited by the drawing task and the picture-naming task in Experiment 3 would be expected to overshoot their combined effect.

Method

Participants.—Sixty Spanish-English bilingual participants (20 men, 40 women) were recruited from the same sources as in Experiments 1 and 2, with the restriction that they had not participated in a previous picture naming or translation experiment. They ranged in age from 17 to 42 (*Mdn* = 20), and all but 1 reported Hispanic ethnicity. Fifty had learned Spanish first, 2 had learned English first, and 8 had learned both languages simultaneously from early childhood. The median age of second language acquisition was 5 years. The dominant language was English for 39 and Spanish for 21 participants. They reported using English 53.5% of the time, Spanish 32.9% of the time, and a mixture 13.4% of the time over the last month (other languages less than 1%); this pattern corresponded to using the dominant language 54.5% of the time and the non-dominant 31.9% of the time.

Design.—As in Experiment 2, the experimental manipulations constituted a 5 (encoding condition) × 2 (final translation direction) within-subjects factorial design. The four critical encoding conditions were word-cued picture drawing (meant to prime word comprehension), picture naming (meant to prime word production), both tasks combined (meant to prime both processes), and neither task (not presented). These four conditions can be considered a 2 (stimulus word drawn or not) × 2 (picture named or not) factorial design. The fifth encoding condition was identical translation.

Materials.—Starting with a set of 288 items deemed appropriate for both picture naming and translation tasks, we piloted the sketching task and excluded items that were particularly difficult to sketch quickly based on the English and/or Spanish word. The remaining set of experimental items consisted of 250 concrete nouns and their corresponding pictures that came primarily from the Snodgrass & Vanderwart (1980) or Pictures Please (Abbate, 1984) sets. The mean letter lengths were 5.6 in English and 6.3 in Spanish, with a median English frequency of 15 per million (Kuçera & Francis, 1967). These items were randomly assigned to 10 sets of 25 items, and the sets were rotated through the 10 experimental conditions across participants using a Latin square to control for specific-item effects.

Procedure.—Participants were tested individually by a bilingual experimenter in sessions lasting approximately one hour, using the same apparatus as in Experiments 1 and 2. At the beginning of the session, participants practiced using the voice relay for a number-naming task. For the naming and translation tasks, RTs were recorded using the microphone and voice relay, and the experimenter noted any unexpected responses or voice relay misfires on a pre-printed worksheet with a list of the expected responses. For the drawing task, words appeared on the screen one at a time, and the participant drew each picture on a 3” × 5” note pad, one picture per page. Upon completion of each sketch, the participant turned the page and pressed a button to initiate presentation of the next word. For this task, participants were instructed to draw quick sketches that would capture the critical features of the object named, but not to spend more than a few seconds on each sketch. If the word was unknown to the participant, they were to write a question mark on the page.

In the encoding phase, six blocks of trials were grouped by response language. In each language, 50 pictures were named, 50 words were used to cue picture drawing, and 25 words were translated. (Twenty-five items were both named and drawn on separate trials for the combined condition.) The orders of languages and tasks at encoding were counterbalanced. Each encoding phase block had 4 practice trials followed by the experimental items. In the test phase, 125 words were translated from English to Spanish, and 125 words were translated from Spanish to English, with the language order counterbalanced. Each of these blocks contained 25 items whose pictures were named at encoding, 25 items drawn at encoding, 25 items both named and drawn at encoding, 25 items translated at encoding, and 25 new items. At the end of the session, participants completed a language background questionnaire and were debriefed.

Results

Scoring of picture drawing responses.—Picture drawing responses were classified into three categories: adequate, not adequate, or no response. Interrater reliability based on 1000 sketches (from the first 10 participants) was high (Cohen’s κ = .88). Across all participants, adequate drawings were produced for on average 94.5% of drawing trials.

Data Processing.—Data were trimmed in the same manner as for Experiments 1 and 2, resulting in the exclusion of 15.3% (*SD* = 9.1) of test phase trials as response errors, 1.8% as machine errors, 6.3% as spoiled trials, and 4.9% as outliers. The spoiled trials included items for which the corresponding encoding phase response was unacceptable (3.6%), inconsistent with the test phase response (0.7%), or had invalid timing (1.2%), and trials for which the expected response or its translation was given as an error response to another item (0.8%). Thus, 71.8% were both correct and valid for the final analysis, on average 18 trials per cell per participant.

Response Times.—Encoding phase RTs and error rates are given in Table 1. Test phase RTs and error rates are given in Table 4 as a function of encoding condition and final response language. New-item RTs for L2-L1 and L1-L2 translation did not differ reliably, $t(59) = 1.297$, $p = .200$. However, the proficiency difference was evident in the error rates ($M = 14.5\%$ in L1 vs. $M = 20.0\%$ in L2), $t(59) = 3.0093$, $p = .003$. Priming scores are illustrated in Figure 5. Priming was substantial and statistically reliable in all repeated conditions (ps $< .002$) except for the drawing only condition ($p = .06$).

The effects of practicing word comprehension and word production were analyzed in a 2 (stimulus word drawn or not) × 2 (picture named or not) × 2 (translation response language) ANOVA. The main effect of drawing the stimulus word to practice word comprehension was significant, $F(1, 59) = 7.458$, $MSE = 31319$, $p = .008$, as was the main effect of naming the picture to practice word production, $F(1, 59) = 124.263$, $MSE = 27879$, $p < .001$. The interaction of these factors on RT did not approach statistical significance, $F < 1$. In other words, the combined effect of prior drawing and prior picture naming (214 ms) did not differ from the sum of the individual effects (44 ms + 170 ms = 214 ms). The effect of prior word-cued drawing (word comprehension practice) did not interact with language, $F < 1$. However, the effect of prior picture naming (word production practice) did interact with language, with a greater benefit in L2 than in L1, $F(1, 59) = 5.947$, $MSE = 43221$, $p = .018$. The three-way interaction did not approach significance, $F < 1$.

In identical repetition conditions, priming was stronger for L1-L2 translation than for L2-L1 translation, $t(59) = 2.375$, $p = .021$. A comparison of the identical translation (279 ms) and the combined conditions (214 ms) showed that about 65 ms of the identical priming effect was left unaccounted for when these partial priming tasks were combined, which was a significant shortfall, $F(1, 59) = 15.698$, $MSE = 15917$, $p < .001$.

Test phase error rates also varied as a function of the language and encoding conditions. When final translation responses were given in L2, error rates for repeated items were significantly reduced relative to new items in conditions that required producing the response word (the naming, combined, and translation conditions, ps $< .05$). When final translation responses were in L1, these effects were not as strong (only significant for combined condition, $p < .05$). No error rate reduction was observed for the condition that only required comprehending the stimulus word (drawing condition, $p = .60$).

Discussion

As in Experiment 2, the encoding tasks meant to prime word comprehension and word production tasks were linearly independent. However, even with the drawing task, the combined priming effects associated with word comprehension and word production fell short of the effect observed for identical translation repetitions. In fact, the word-cued drawing task elicited no more priming than the semantic classification task did in Experiment 2. Thus, it appears that the critical factor in priming word comprehension is not merely the specificity of conceptual access. The level of repetition priming remained less than half of the level obtained in an experiment in which word comprehension processes were practiced based on prior translation to a neutral 3rd language (Francis & Gallard, 2005).

Somehow, the type of access needed for translation to a neutral 3rd language is more compatible with the final translation task than the access needed for picture drawing. One possible explanation is that word-cued picture drawing (or word classification) and translation tasks involve access to different domains of semantic knowledge. Dependence on different domains of semantic knowledge were cited as an explanation for why priming of semantic classification is reduced when the basis of the decision changes from encoding to test (Thompson-Schill & Gabrieli, 1999; Vriezen et al., 1995; Xiong et al., 2003). Perhaps when preparing to draw the object that corresponds to a stimulus word, the semantic information accessed is primarily the structural features of the object, properties that would not be relevant for word translation. We will return to this issue in the General Discussion.

The results are clearly inconsistent with the possibility that word-cued picture drawing induced intentional covert translation to the eventual target language. If such translation had occurred, the facilitation from picture drawing ought to have been greater than what was observed; specifically, it should have exceeded the difference between the identical repetition and picture naming conditions, or 109 ms. Also, the overlap of word retrieval processes in covert translation and picture naming would have caused a subadditive interaction (see Experiment 4 for a test of this assertion). Specifically, the sum of the individual effects would have exceeded the effect in the combined condition. It is possible that the words were automatically activated to some extent, but if they were, there was no lasting effect.

In planning and interpreting Experiments 2 and 3, we assumed that if processes for the two encoding tasks overlapped, the combined priming effects would have been subadditive, with the sum of the individual effects greater than the combined condition effect. Also, to the extent that a second exposure would confer an additional benefit, we expected the combined effect to exceed the identical repetition effect. These assumptions were directly tested in Experiment 4, which was also designed to estimate the contribution of articulation processes to the word production component of repetition priming in word translation.

Experiment 4

The additive-factors logic applied to Experiments 2 and 3 entailed an important assumption based on the idea that each successive practice trial for a process has a diminished benefit relative to the previous practice trial. Specifically, we assumed that if the processes for the two encoding tasks overlapped, the sum of the individual effects would have exceeded the combined-condition effect, thus exhibiting a subadditive interaction. Based on this premise, a lack of interaction would be inferred to indicate that the processes are independent and do not overlap. Another assumption was that if the processes overlapped, the combined effect would exceed the identical effect to the extent that a second exposure provides additional benefit, but it was unknown whether there would be any benefit to a second exposure. As explained in the introduction, for identical repetition in picture naming, multiple practice trials lead to greater priming than a single practice trial, with diminishing returns for each additional repetition, and similar findings have been observed for repeated verb generation (e.g., Raichle et al., 1994; Seger et al., 1999) and translation verification (Izura & Ellis, 2004). These findings suggest that to the extent there is further room for improvement after the first experimental practice trial, a second exposure before final test will be beneficial; however, this possibility has not been tested in translation production or with two encoding tasks whose processes only partially overlap each other and the test task. Experiment 4 tests whether combining encoding tasks with processes that overlap would indeed produce a subadditive interaction and whether the combined effect would overshoot the level of priming in the identical repetition conditions.

To maximize the chances of finding both subadditivity and a benefit from a second exposure, tasks were chosen to have an overlapping set of processes that make a large contribution to repetition priming. The component of translation that appears to be most susceptible to priming is word retrieval from the concept. Therefore, this process was chosen as the one to perform twice at encoding, and the encoding tasks were written word translation and picture naming, which both require the completion of word retrieval processes.

In addition to testing these logical assumptions, Experiment 4 furthers the decomposition of processes facilitated in repeated translation by estimating the contribution of modality-specific production processes to repetition priming in spoken translation. Written translation requires all of the processes used for spoken translation except for those associated with retrieving the phonological word form (lexeme) and articulating the overt response. If written translation at encoding produces less facilitation than identical spoken translation, we can conclude that modality-specific lexeme retrieval or articulation processes are facilitated in repeated translation. As explained in the introduction, previous research with monolinguals suggests that articulation gains little if any benefit from prior practice, presumably because articulation is overlearned. However, in bilinguals, articulation may not be overlearned, particularly in the less fluent language, and its potential for item-specific learning has not been directly addressed. The propensity for lexeme retrieval to benefit from repetition in a more or less fluent language is unknown.

Method

Participants.—Sixty Spanish-English bilingual participants (19 men, 41 women) were recruited from the same sources as in Experiments 1, 2, and 3, with the restriction that they had not participated in a previous picture naming or translation experiment. They ranged in age from 17 to 32 (Mdn = 19), and all reported Hispanic ethnicity. According to self-report, 51 had learned Spanish first, 4 had learned English first, and 5 had learned both languages simultaneously from early childhood. The median age of second language acquisition was 7 years. The dominant language was classified as English for 33 and Spanish for 27 participants. They reported using English 45.6% of the time, Spanish 40.6% of the time, and a mixture 13.8% of the time over the last month; this pattern corresponded to using the dominant language 55.6% of the time and the nondominant language 30.6% of the time. There were 6 additional students who completed the protocol but were excluded due to poor performance and replaced.

Design, Materials, and Procedure.—The design, materials, and procedure were identical to those of Experiment 3 except that instead of drawing pictures based on word cues, participants were instructed to write the translation of each word.

Results

Data Processing.—Data were processed in the same manner as for Experiment 3, resulting in the exclusion of 15.1% (*SD* = 6.9) of test phase trials as response errors, 2.2% as machine errors, 7.4% as spoiled trials, and 4.8% as outliers. (The breakdown of spoiled trials was 4.0% with a response error at encoding, 1.4% with a timing error at encoding, 1.4% inconsistent with the encoding phase response, and 0.6% given as error response to another item.) Thus, 70.4% were both correct and valid for the final analysis, on average 17.6 trials per cell per participant.

Response Times.—Encoding phase RTs and error rates are given in Table 1. Mean test phase translation RTs are shown in Table 5 as a function of encoding condition and final response language. New-item RTs for L2-L1 and L1-L2 translation did not differ reliably, $t(59) = 1.063$, $p = .292$. However, the proficiency difference was evident in the error rates (16.0% vs. 22.3%), $t(59) = 4.0147$, $p < .001$. Priming scores are illustrated in Figure 6. Repeated items were translated faster than new items for all encoding conditions (ps < .001).

The main analysis was a 2 (stimulus word translation written or not) × 2 (picture named or not) × 2 (response language) ANOVA. The main effect of writing the translation was significant, $F(1, 59) = 195.18$, $MSE = 34005$, $p < .001$, as was the main effect of picture naming, $F(1, 59) = 86.72$, $MSE = 22050$, $p < .001$. The facilitating effects of the two encoding tasks on RT interacted, $F(1, 59) = 24.32$, $MSE = 21376$, $p < .001$. More specifically, the combined effect (361 ms) was less than the sum of the individual effects (301 + 192 = 493 ms); that is, the combined effects were subadditive. The effect of practicing written translation was stronger when translating from L2 to L1, $F(1, 59) = 5.53$, $MSE = 22633$, $p = .022$. However, in contrast to Experiments 2 and 3, the interaction of picture naming (word production) practice with response language was not statistically reliable, $F(1, 59) = 1.25$, $MSE = 23428$, $p = .269$. There was no indication of a three-way interaction, $F < 1$.

In identical repetition conditions, priming did not differ reliably across translation directions, $t(59) =.347$, $p = .729$. A comparison of priming in the identical translation condition (332 ms) to priming in the combined condition (361 ms) shows that the combined condition effect overshot the identical repetition effect by 29 ms, but this difference was only marginally significant, $F(1, 59) = 3.380$, $MSE = 15552$, $p = .071$. This effect would indicate additional benefit conferred by a second exposure. Also note that in both languages, the combined condition elicited greater priming than either individual condition alone (ps < .001).

To examine the contributions of articulation processes, a 2 (translation response mode) × 2 (translation direction) repeated measures ANOVA was performed on priming scores from the written and spoken (identical) translation conditions in both directions. Priming from written translation alone fell short of the identical case by 31 ms, $F(1, 59) = 5.009$, $MSE = 11366$, $p = .029$. This difference was qualified by a significant interaction of response mode and direction, $F(1, 59) = 4.879$, $MSE = 22166$, $p = .031$. This interaction reflected a difference of 73 ms for L1-L2 translation, $t = 2.947$, $p = .005$, but a difference of –12 for L2-L1 translation, $t = .521$, $p = .604$.

Test phase error rates also varied as a function of the language and encoding conditions. For both languages, error rates for repeated items were significantly reduced relative to new items in all conditions (ps < .01). Note that in Experiment 4, unlike Experiments 2 and 3, all repeated conditions involved repetition of word retrieval processes.

Discussion

Written translation, picture naming, and spoken translation encoding tasks elicited repetition priming in spoken word translation. Repetition priming effects based on written translation and picture naming encoding tasks were not independent; the effects exhibited a subadditive interaction, with the combined condition effect falling 132 ms short of the sum of the individual effects. This pattern was clearly consistent with the expectations for overlapping, nonindependent processes (as shown in the third model of Figure 2) and can be attributed to the word retrieval processes shared by written translation and spoken picture naming tasks and the diminishing returns associated with a second exposure. Also, the results suggest that performing both encoding tasks led to stronger priming (by 29 ms) than did identical spoken translation, but this effect was only marginally significant. This effect suggests that the second repetition of the word retrieval processes incremented facilitation. However, because it is a much weaker effect than the subadditivity, it may not be a useful indicator of process overlap.

As expected, written translation primed spoken translation but not as much as did identical repetition of spoken translation at encoding and test. In L2, the contribution of modality-specific processes was estimated at 73 ms, but there was no evidence of a contribution in L1. The lack of modality-specific priming in L1 is consistent with single language studies that showed little if any priming based on repetition of articulation (e.g., Durso & Johnson, 1979; Wheeldon & Monsell, 1992). It therefore appears that modality-specific processes of lexeme retrieval and articulation are “overlearned” in L1 and have very little potential for facilitation, but they still have room for improvement in L2. It seems implausible that articulation per se accounts for the entire 73 ms modality-specific effect in L2; therefore, some of the effect must be attributable to lexeme retrieval. In summary, the modality-general processes associated with accessing the lemma, a modality-general word representation, were primed in both languages, but the modality-specific processes associated with lexeme retrieval were primed only in L2.

General Discussion

In the following sections, the results are summarized and discussed with respect to three main themes. The first section summarizes the main findings, with a focus on the comprehension and production processes that were facilitated, their degree of interaction or independence from each other, and the consequences of repeating overlapping sets of processes. The second section covers implications of the results for human memory, including the types of memory dissociated and the basis of repetition priming. In the third section, implications for bilingual language processing are discussed in terms of intentional and incidental access to nontarget languages.

Repetition Priming in Word Comprehension and Production

Processes Facilitated.—Spoken translation exhibited large facilitation effects for items that were identically translated at encoding relative to those items that were new at test (Experiments 2, 3, and 4). Repetition priming effects were also observed in the partial repetition conditions. Word-classification and picture-drawing tasks meant to facilitate word comprehension processes of translation elicited substantial priming (Experiments 1, 2, and 3). However, this priming was not as strong as would be expected if all word comprehension processes of translation had been primed, and it fell far short of the indirect estimates obtained by Francis and Sáenz (2007) and the effects observed following translation to a neutral 3rd language (Francis & Gallard, 2005).

The picture-naming task used to facilitate word production processes of translation also elicited substantial priming (Experiments 2, 3, 4), with stronger priming when responding in L2. Written translation, a task meant to facilitate both word comprehension and word retrieval processes of spoken translation but not modality-specific lexeme-retrieval and articulation processes, also led to strong facilitation in spoken translation, but less than that observed with identical spoken translation (Experiment 4); however, the reduction was observed only when responses were made in L2. Taken together, these repetition-priming effects from partial repetition conditions indicate that word-comprehension, lemma-retrieval, and lexeme-retrieval processes contributed to repetition priming in word translation, but lexeme retrieval contributed only in L2.

In previous research, the difference between covert and overt production was attributed to articulation, as were the small to non-existent repetition effects from picture naming to word naming and in word generation for homonyms. However, especially given the magnitude of the L2 effect obtained in the present study, it seemed implausible that articulation per se could account for the entire effect. In a fluent L2, articulation ought to be at least close to over-learned. Unlike the previous studies, the present study involved a change in output modality rather than covert vocal production or repetition of articulation in the absence of other common processes. Spoken and written production processes, and therefore spoken and written translation, diverge after access to the lemma. It is clear that there is a modality-specific component of word production that is over-learned in L1 but not over-learned in L2, and the most plausible process to account for this difference is lexeme retrieval.

Interactions and Additivity.—Experiments 2 and 3 tested whether the contributions of word comprehension and word production processes to repetition priming interacted. As it turns out, the factorial combination of encoding tasks meant to facilitate each set of processes did not reveal interactions. More importantly, the discrepancy between the sum of the individual effects and the priming effect observed when the same item was both classified (or drawn) and named at encoding was a mere 7.4 ms in Experiment 2 and 0.2 ms in Experiment 3; for comparison, the combined-condition means were 201 ms and 214 ms, respectively. Essentially, the effects were linearly additive.

To increase the chances of detecting any substantial interactions that might exist, the experiments were run with more observations than are typical for either bilingual or repetition priming experiments. For the power analyses reported here, effect sizes were computed using Cohen's d for ease of interpretation. To illustrate the sensitivity of the designs, Experiments 2, 3, and 4 had 80% power to detect small-to-medium effects of sizes $d = .30$, .37, and .37, respectively. All had over 99% power to detect a large effect ($d = .80$), 97–99% power to detect a medium effect ($d = .50$), and 76–91% power to detect a small-to-medium effect ($d = .35$). The interactions in Experiments 2 and 3 had very small effect sizes of $d = .04$ and $d = .00$, respectively. (In contrast, the expected interaction in Experiment 4 had a large effect size of $d = .90$.) The important point here is not that we can be sure that comprehension and production processes in translation are independent and non-overlapping, but rather that the interaction effects are so small that a linearly additive model does well in explaining the data.

Although the results suggest that comprehension in one language and production in another are independent and do not facilitate each other, these findings do not by any means indicate that comprehension and production *within* a language are independent. In fact, several previous findings indicate that comprehension and production do facilitate each other within a language. For example, picture naming in L1 facilitated later L1-L2 translation (Sholl et al., 1995); L2-L1 translation facilitated L1-L2 translation and vice-versa (Francis et al., 2010); and L1-L2 translation facilitated L1 picture naming and L2-L1 translation facilitated L2 picture naming (Francis et al., 2008).

Demonstrating that Subadditivity is Possible.—Experiment 4 provided evidence that the priming effects elicited by encoding tasks with overlapping processes interacted, exhibiting subadditivity. The sum of the facilitation effects elicited by written translation and picture naming, tasks that share word retrieval processes with each other and the test task of spoken translation, was far greater (132 ms greater) than the effect observed in the combined condition. Therefore, it was reasonable to expect that if the sets of processes engaged by the encoding tasks meant to facilitate comprehension and production in Experiment 2 and 3 had overlapped, there would have been a subadditive interaction. The results of Experiment 4 also suggest that performing a combination of two encoding tasks that have overlapping processes leads to stronger priming than identical repetition, thus indicating some benefit from practicing those processes a second time. However, this difference was relatively small (29 ms) and only marginally significant. Because it was a much weaker effect than the subadditivity effect, it was not a very useful indicator of process overlap, and a failure to detect such a small difference would not be a reliable indicator of independence.

The Missing Component in Comprehension.—In Experiments 2 and 3, both the combined condition effect and the sum of the individual effects of the encoding tasks meant to facilitate comprehension and production fell short of the magnitude of the effect observed with identical repetition. This shortfall could not be explained by imprecise conceptual access, because picture drawing (Experiment 3) must require it. Instead, it may be the case that the domain of semantic information accessed for translation differs from that used for picture drawing or word comprehension. The incomplete facilitation of word comprehension processes following semantic classification and word-cued drawing tasks may be analogous to the incomplete facilitation observed between semantic classification tasks with different decision bases (e.g., Franks et al., 2000; Thompson-Schill & Gabrieli, 1999). Picture drawing would appear to require access to key visual features of an object, whereas semantic classification requires access to categorical or associative information, and translation requires access to the precise “core” concept.

The “missing component” does not call into question the independence of the sets of processes that were in fact facilitated, because the critical test there was additivity in their combination. However the existence of a missing component does raise the important question of what that component could be, whether it is possible to facilitate it, and whether, if facilitated, its effect would be independent of priming in word production. We can reason about the nature of the missing component. Semantic classification of words, word-cued picture drawing, and translation to a “neutral” third language all require perception of the same stimulus, access to the same orthographic word form (grapheme), and access to the same lemma. However, from there, the processing routes may diverge because the tasks require the retrieval of different semantic information. For semantic classification, category memberships or semantic attributes are needed; for word-cued picture drawing, it would be the visual characteristics of the object; for translation to a third language, it would be access to the core meaning/concept. This is not to say that the other aspects are not co-activated, but they are not selected because they are not critical for task completion. The shortfall, we believe, is in accessing the core concept needed for translation once the lemma of the stimulus word is accessed.

In a previous study, we were able to facilitate word comprehension fully, including the component that was not selectively primed in the present study. In an experiment with English-Spanish-French trilinguals, translation from English to Spanish produced 117 ms of priming in later English-French translation, and similarly, translation from French to Spanish produced 173 in later French-English translation. These effects did vary by dominance, with greater priming for comprehension in the less fluent language. Also, this effect plus the effect obtained following translation to a common response language (e.g., Spanish-French to English-French) added up to approximately (95–96% of) the effect obtained with identical repetition. One could argue that translation is different, because activation might have spread to translation equivalent in the eventual target language even at study, but as we have shown in the present series of experiments, such incidental activations do not lead to long-term facilitation.

Implications for Memory

Types of Implicit Memory and Repetition Priming.—These dissociations of word comprehension and word production support a distinction between identification and production forms of repetition priming. Gabrieli has claimed that this distinction is fundamental in the functional organization of implicit memory by showing that it predicted which forms of priming were impaired in early Alzheimer's disease and which were affected by attentional manipulations (Gabrieli et al., 1999). However, in the present study we departed somewhat from Gabrieli's approach, in that rather than classify entire tasks as identification or production tasks, the single task of translation was considered to have its own dissociable identification (comprehension) and production components. Operationally, this means that the distinction was made within rather than across repetition priming paradigms. As can be seen by comparing priming for the two directions of translation in Experiments 2 and 3, the relative contributions of comprehension and production processes to repetition priming in translation varied as a function of proficiency in the stimulus and response languages. Averaging across Experiments 2, 3, and 4, the proportion of the identical repetition effect attributable to word production was 49% in L1 (L2-L1 translation) and 64% in L2 (L1-L2 translation). In a study with a larger proficiency difference between languages, estimates were 51% in L1 and 76% in L3 (Francis & Gallard, 2005). This result is consistent with the idea that production is the component that is less well learned and can benefit more from practice.

Basis of Repetition Priming.—There has been disagreement among researchers as to why RT decreases when items are repeated from encoding to test, that is, where exactly the time is saved to produce a shorter RT. As explained in the introduction, previous research has shown that repetition priming is not merely an artifact of residual activation from the encoding episode, but rather a long-term learning effect. The priming observed following partial repetitions (when stimulus or response differs) in previous studies and the present study also ruled out the possibility that repetition priming reflects the learning of a simple stimulus-response pairing or simple recall of the previous response. Predictions in this study were made based on the idea that speeded responses arise because the component processes are executed more quickly. However, we also evaluated an alternative explanation based on a qualitative change in processing route from a concept-mediated route at encoding to a more direct word-to-word route at test. Such a change would be unexpected given past evidence supporting a learning trajectory from word mediation to concept mediation as late bilinguals become more proficient in a second language (Kroll & Tokowicz, 2001). We nevertheless considered this possibility, because changes in processing route or neural circuitry have been offered as explanations of repetition priming in verb generation and picture naming in neural response (Raichle et al., 1994; van Turrennout et al., 2003), although these claims have not been adequately tested.

The linear independence of the partial repetitions in Experiments 2 and 3 indicates that there were no macro-level cognitive shortcuts. Consistent with this conclusion, a previous study showed that priming of word comprehension and priming of word production in translation following translation to and from a 3rd language accounted for over 95% of the effect obtained with identical repetition (Francis & Gallard, 2005). A route change was also ruled out for picture naming by showing that manipulations that affected object identification and word production components were linearly additive and accounted for the full effect obtained with identical repetition (Francis et al., 2008). Instead, the observed patterns of priming indicate that each nonoverlearned cognitive process exhibits learning; both word comprehension and word production are executed more quickly when repeated.

Implications for Bilingual Language Processing

An important question in bilingual word tasks is whether processing in one language leads to covert translation or incidental co-activation of the translation equivalent. Previous research has shown that intentional covert access has consequences for later processing. Specifically, intentional covert word production led to full priming of later overt production in both picture naming (Brown et al., 1991) and verb generation (Seger et al., 1999). In contrast, as explained in the introduction, incidental co-activation of translation equivalents has short-term consequences for immediate comprehension or production (e.g., Costa et al., 1999; Schwartz & Fontes, 2008), whereas there is no evidence to date that incidental co-activation has long-term consequences. Here, we examine whether each of the three non-translation encoding tasks, picture naming, semantic classification of words, and word-cued picture drawing is subject to covert translation or lasting effects of incidental co-activation.

The independence of the effects of picture naming and the effects of semantic classification and word-cued picture drawing on later translation (Experiments 2 and 3) indicate that picture naming did not induce intentional name retrieval in the nontarget language. If word-cued semantic classification or picture drawing had elicited intentional covert translation (even if not necessary for the task), they would have facilitated not only word comprehension processes in the stimulus language but also word retrieval in the translation response language.

Three aspects of the data indicated that intentional covert translation did not occur. In Experiment 1, covert translation during semantic classification would have made priming from classification to translation stronger than priming from translation to classification, but these effects were approximately equivalent. This finding parallels the equivalent between-task effects for semantic classification of pictures and picture naming, which indicated that semantic classification of pictures did not elicit intentional covert naming (Francis et al., 2008). Second, in Experiments 2 and 3, the semantic classification and word-cued picture drawing tasks would have elicited a priming effect comparable to that observed with written translation in Experiment 4, a task that shares stimulus word comprehension and target word retrieval with spoken translation. Contrary to this expectation, they elicited only about 20% of the effect observed for written translation. Finally, in Experiments 2 and 3, the combination of these tasks with picture naming would have been subadditive because of overlapping word retrieval processes, but the effects were additive. Therefore, it can be concluded that intentional covert translation did not occur.

Research on dual task performance suggests that it is not possible to select (prepare) two different responses simultaneously. In the case of word production, a processing bottleneck occurs during retrieval of the lemma and phonological word form, the response selection components, but not in articulation, which is execution of the response (Ferreira & Pashler, 2002). The fast-paced picture-naming task at encoding in Experiments 2, 3, and 4 may not have allowed enough time to also select the corresponding word in the other language. Similarly, with the bottleneck that occurs in selection of a semantic classification response, the semantic-classification encoding task in Experiments 1 and 2 may have been too fast paced to allow for covert selection of the translation equivalent.

It is still possible that picture naming, semantic classification of words, and word-cued picture drawing produced activation that spread to translation-equivalent words in the nontarget language in a manner incidental to the completion of the required tasks, but if such activation occurred, its effects dissipated across the retention interval. On possible explanation is that activation spreads to the nontarget language but no selection occurs, consistent with a model of bilingual picture naming and lexical access in which activation spreads to words in both languages, but only words in the target language compete for selection (Costa et al., 1999). Intentional selection of a verbal response may be necessary for long-term word-production priming to occur.

Conclusions

Word translation exhibits repetition priming that is based on a combination of word comprehension and word production processes. Thus, a single exposure leads to long-term facilitation in both sets of processes. The comprehension and production components make independent contributions, indicating that a model treating these processes as independent and sequential is adequate to explain the data. This independence supports a distinction between identification and production forms of repetition priming. The patterns of priming with partial repetition indicate that long-term repetition priming is based on speeding of the component processes, not a change in processing routes. Picture naming, semantic classification, and word-cued picture drawing tasks do not elicit intentional access to the non-target language, and any incidental co-activation that may have occurred did not have a lasting effect.

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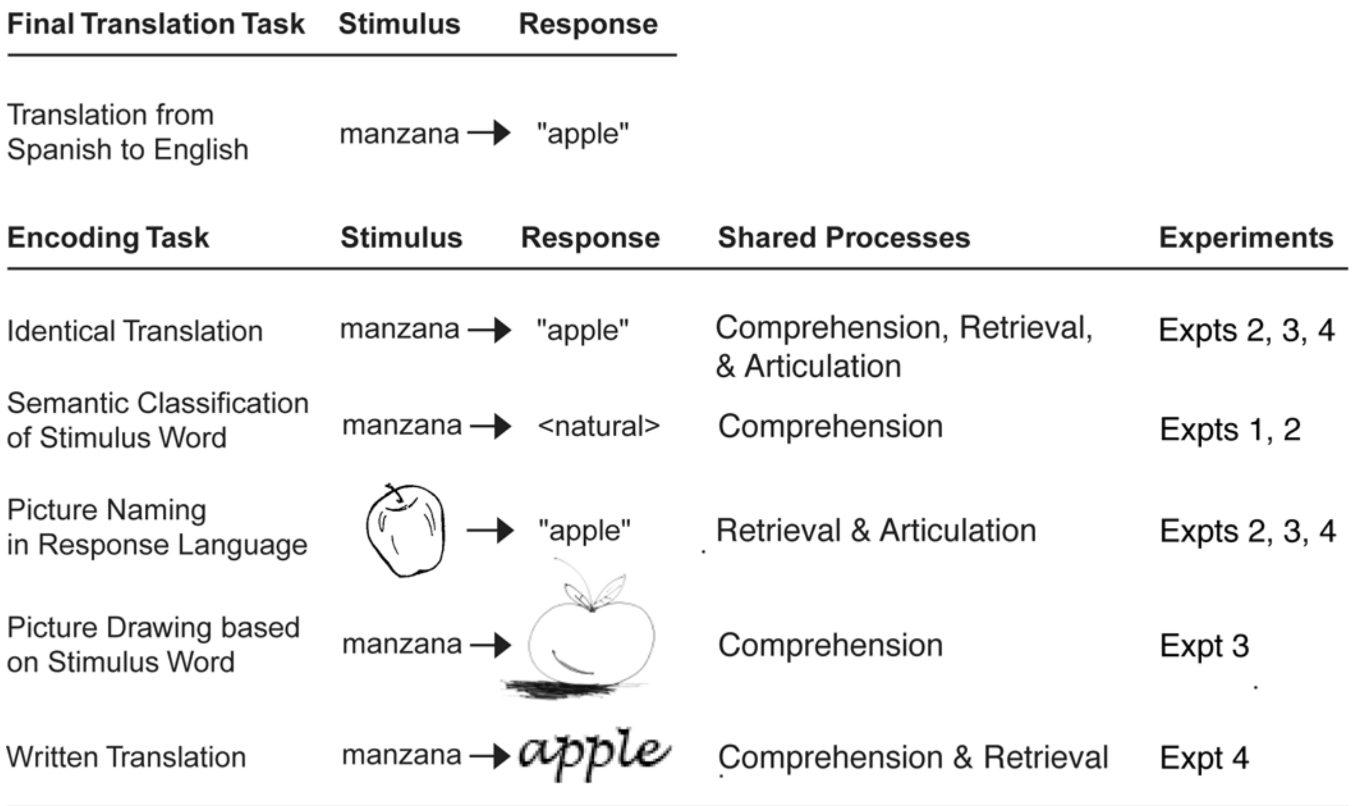

Figure 1.
Examples of encoding tasks for key experimental conditions when the test task is translation from Spanish to English.

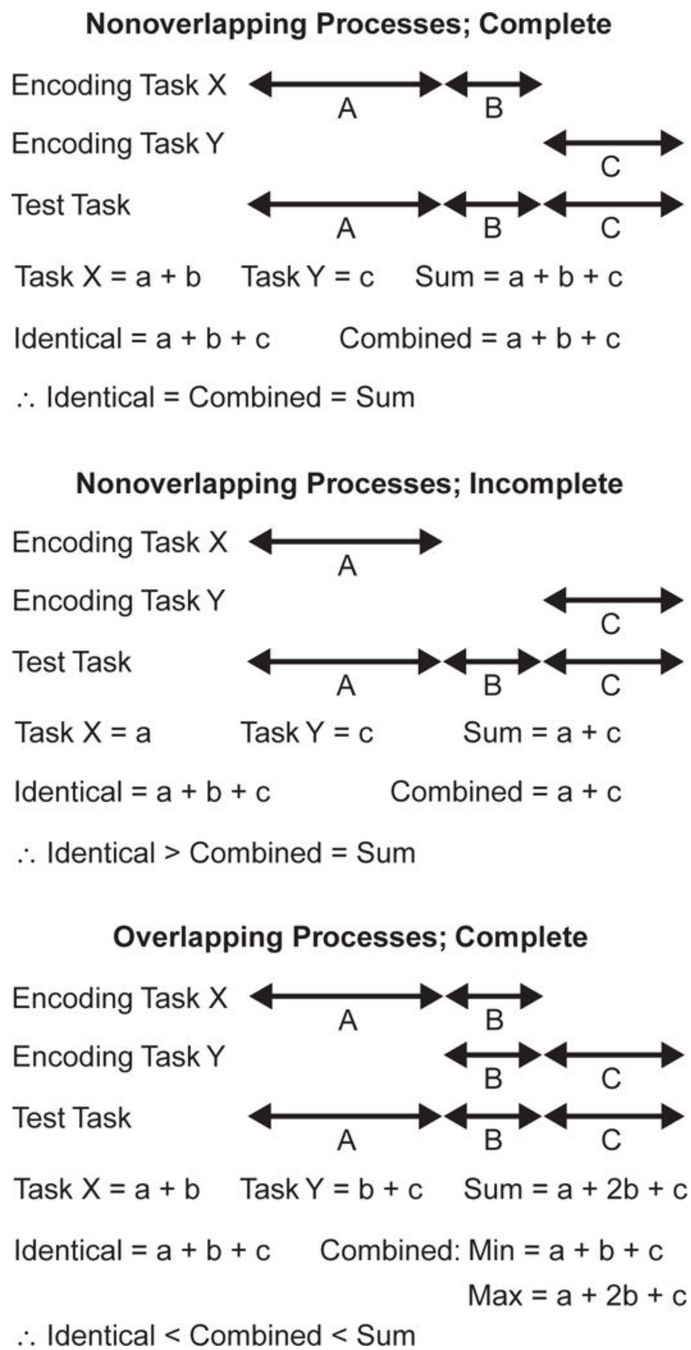

Figure 2.

Additive factors logic as applied to repetition priming in three situations. In each case, Task X and Task Y are encoding tasks that have processes in common with a test task that requires processes A, B, and C. Task X begins with the same stimulus as the test task; Task Y ends with the same response as the test task. These tasks are performed at encoding either individually or in combination for any given item. Quantities a, b, and c represent the facilitation obtained when process A, B, or C, respectively, has been practiced once in the encoding phase. Sum = sum of the facilitation effects obtained for Task X alone and Task Y alone; Identical = facilitation for identical repetition of the test task; Combined = facilitation when both Task X and Task Y are both performed on the same item before the final test task. Expectations of facilitation for these three conditions are given for three situations: (1) Processes of Tasks X and Y do not overlap, but together they involve all processes of the Test Task; (2) Processes of Tasks X and Y do not overlap, and together they do not involve all processes of the Test Task; and (3) Processes of Tasks X and Y overlap and together involve all processes of the Test Task. Adapted from Francis, Corral, Jones, and Sáenz (2008).

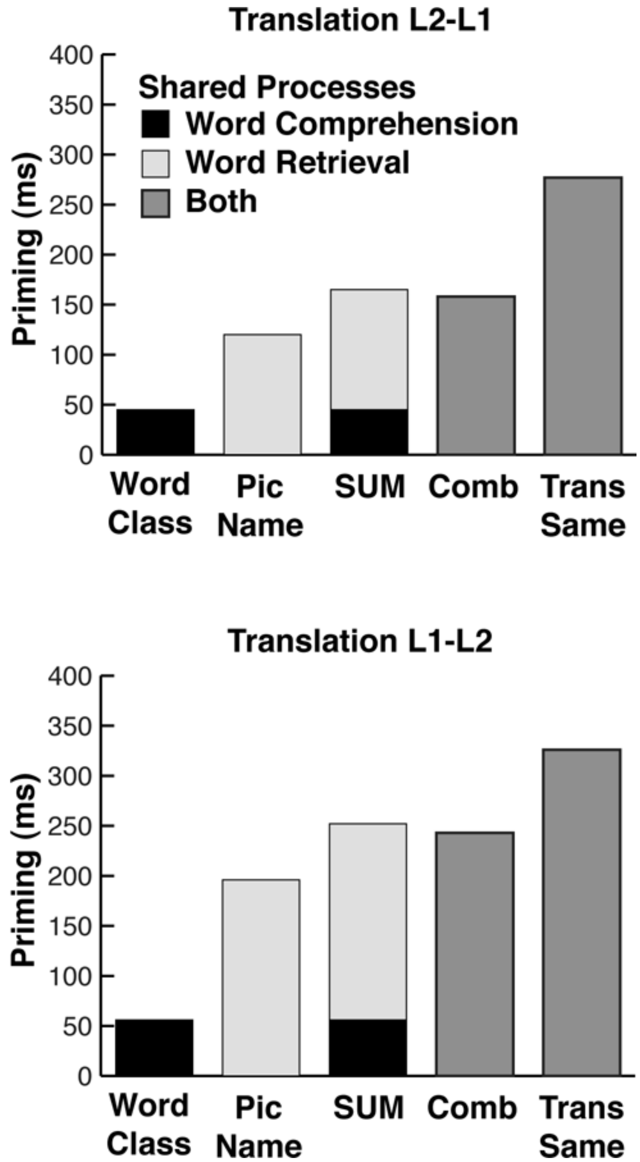

Figure 3.

Repetition priming in Experiment 2 as a function of encoding condition and final translation direction. Word Class = word classification; Pic Name = picture naming; Sum = sum of the effects for word classification and picture naming; Comb = combined condition in which word classification and picture naming are performed on the same items on different trials; Trans Same = translation.

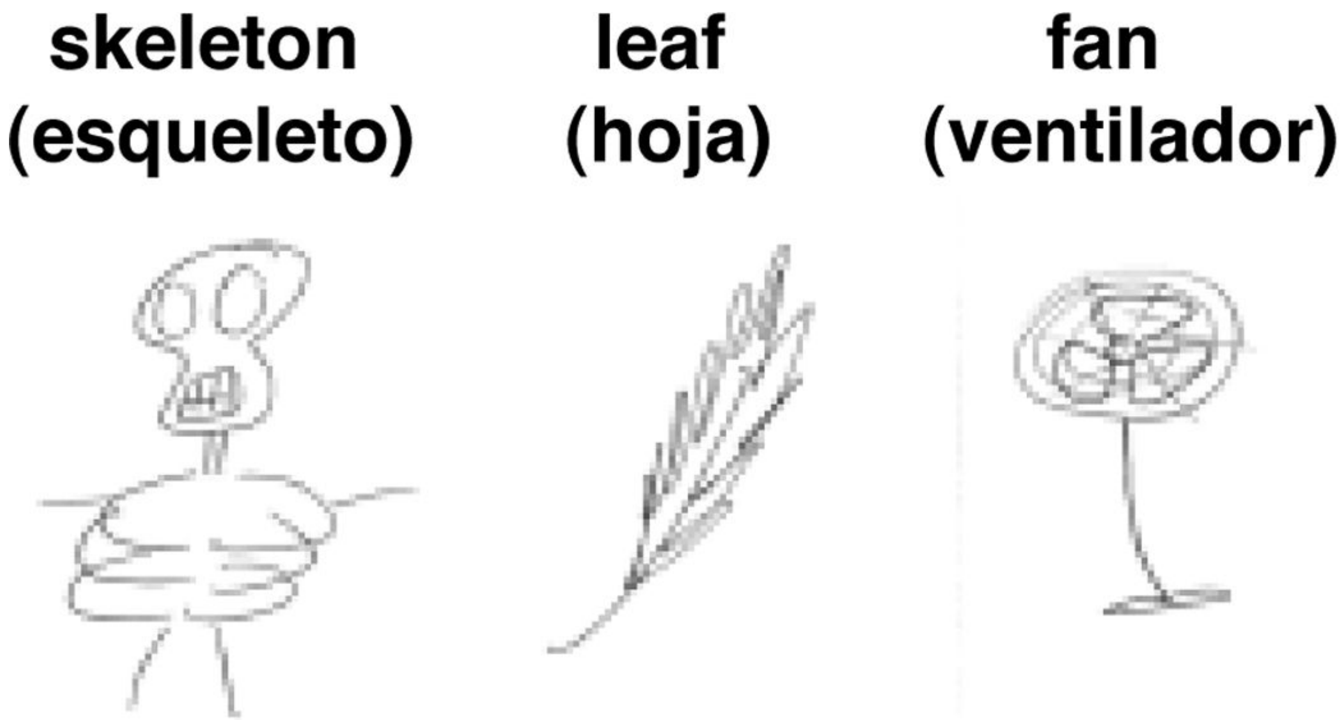

Figure 4.
Examples of sketches produced by participants in the word-cued picture drawing task.

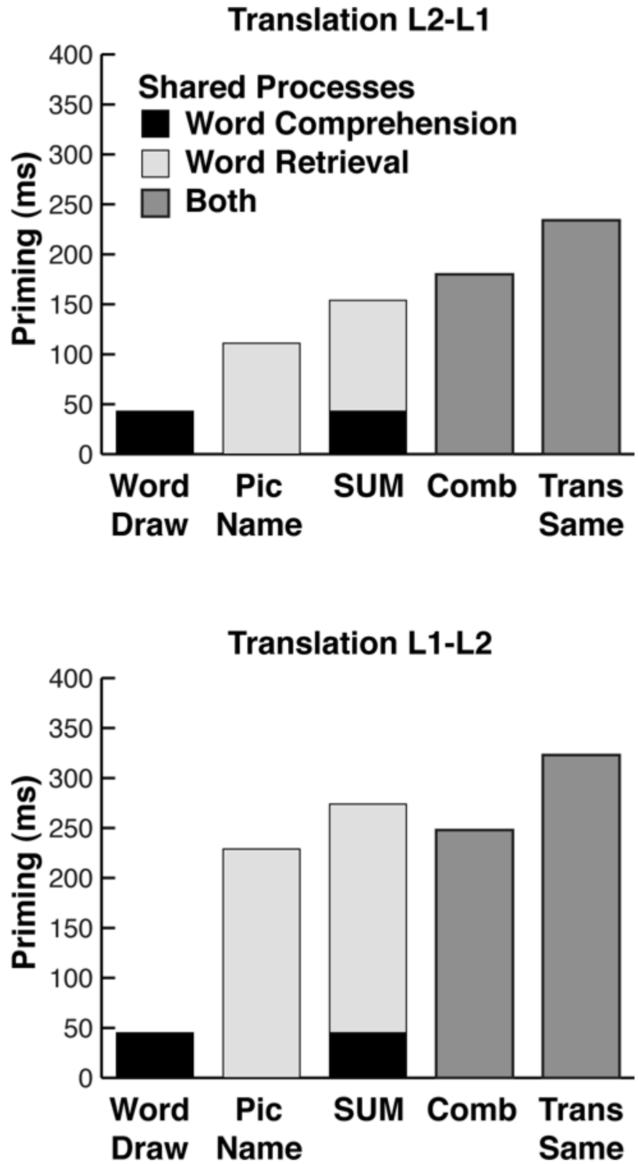

Figure 5.

Repetition priming in Experiment 3 as a function of encoding condition and final translation direction. Word Draw = word-cued picture drawing; Pic Name = picture naming; Sum = sum of the effects for drawing and picture naming; Comb = combined condition in which drawing and picture naming are performed on the same items on different trials; Trans Same = translation.

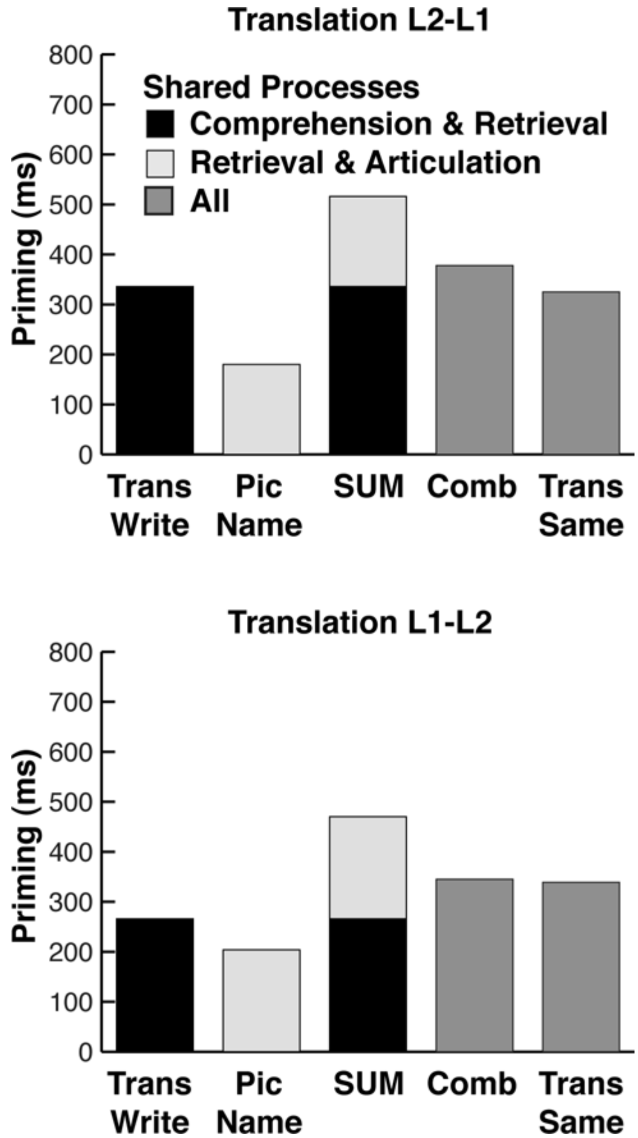

Figure 6.

Repetition priming in Experiment 4 as a function of encoding condition and final translation direction. Trans Write = written translation; Pic Name = picture naming; Sum = sum of the effects for TRW and PN; Comb = combined condition in which written translation and picture naming are performed on the same items on different trials; Trans Same = spoken translation (identical repetition). All = comprehension, retrieval, and articulation; retrieval is practiced twice in the both condition.

Table 1

Encoding Phase RTs and Error Rates as a Function of Task and Response Language in All Experiments.

Experiment / Task	Response Language: English RT (ms)	English ER (%)	Spanish RT (ms)	Spanish ER (%)	L1 RT (ms)	L1 ER (%)	L2 RT (ms)	L2 ER (%)
Experiment 1 (N = 64)								
Translation	1316	18.5	1263	21.6	1295	16.4	1284	23.7
Word Categorization	968	5.1	1102	4.5	965	4.9	1105	4.8
Experiment 2 (N = 90)								
Translation	1214	19.0	1144	21.5	1190	18.4	1168	22.1
Picture Naming	1031	14.2	1124	15.1	991	9.8	1164	19.4
Word Categorization	900	4.1	997	4.7	893	3.7	1005	5.2
Experiment 3 (N = 60)								
Translation	1311	16.1	1230	19.2	1246	14.9	1295	20.3
Picture Naming	1086	10.0	1206	16.6	1026	8.5	1267	18.1
Drawing	---	4.3	---	6.7	---	3.1	---	7.9
Experiment 4 (N = 60)								
Translation (spoken)	1355	16.2	1223	16.5	1267	13.0	1311	19.7
Picture Naming	1119	11.9	1260	16.9	1073	9.3	1306	19.5
Written Translation	---	15.0	---	15.3	---	12.5	---	17.9

Table 2

RTs, Error Rates, and Priming in Experiment 1 as a Function of Task and Stimulus Language.

Encoding Condition	RT (ms)			Error Rate		
Encoding Task → Test Task	**L1[a]**	**L2**	**Overall**	**L1**	**L2**	**Overall**
Not Presented → Word Classification	978	1123	1050	.05	.05	.05
Translation → Word Classification	947	1045	996	.04	.05	.05
Priming	32*	78**	55**	.00	.00	.00
Not Presented → Translation	1444	1418	1431	.22	.16	.19
Word Classification → Translation	1389	1347	1368	.21	.14	.18
Priming	55	71**	63**	.01	.02	.01

*$p < .05$

**$p < .01$

[a]Stimulus language for each item was held constant from study to test.

Table 3

Translation RTs and Error Rates in Experiment 2 as a Function of Encoding Task and Direction of Final Translation.

	RT (ms)			Error Rate		
Encoding Task	**L2-L1**	**L1-L2**	**Overall**	**L2-L1**	**L1-L2**	**Overall**
Not Presented	1344	1362	1353	.19	.24	.21
Word Classification	1299	1307	1303	.17	.25	.21
Picture Naming	1224	1167	1195	.13	.18	.16
Both	1186	1119	1152	.12	.19	.15
Translation (identical)	1067	1036	1051	.15	.19	.17

Table 4

Translation RTs and Error Rates in Experiment 3 as a Function of Encoding Task and Direction of Final Translation.

	RT (ms)			Error Rate		
Encoding Task	**L2-L1**	**L1-L2**	**Overall**	**L2-L1**	**L1-L2**	**Overall**
Not Presented	1373	1420	1397	.15	.20	.17
Word-Cued Picture Drawing	1330	1375	1353	.13	.21	.17
Picture Naming	1263	1191	1227	.13	.15	.14
Both	1194	1172	1183	.10	.17	.14
Translation (identical)	1139	1097	1118	.13	.17	.15

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Table 5

Translation RTs and Error Rates in Experiment 4 as a Function of Encoding Task and Direction of Final Translation.

	RT (ms)			Error Rate		
Encoding Task	**L2-L1**	**L1-L2**	**Overall**	**L2-L1**	**L1-L2**	**Overall**
Not Presented	1455	1412	1434	.16	.22	.19
Written Translation	1118	1147	1133	.13	.18	.15
Picture Naming	1275	1208	1242	.12	.17	.14
Both	1077	1068	1073	.10	.14	.12
Spoken Translation (identical)	1130	1074	1102	.12	.19	.15