Decomposition of Repetition Priming Components in Picture Naming

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Cognitive mechanisms underlying repetition priming in picture naming were decomposed in several experiments. Sets of encoding manipulations meant to selectively prime or reduce priming in object identification or word production components of picture naming were combined factorially to dissociate processes underlying priming in picture naming. Experiments 1, 2, and 3 were conducted with Spanish–English bilingual participants and bilingual materials. Experiments 4, 5A, and 5B were single-language experiments in English or Spanish. A simple process model was used to formalize the theoretical predictions and test them across all experiments simultaneously. Object identification and word production processes were selectively influenced in an additive manner, which suggests that the 2 sets of processes are independent and sequential. The patterns of facilitation support a qualitative model of transfer-appropriate processing in which shared processes from encoding to test are the causal basis and speeded processes are the mechanism of facilitation.

Keywords: repetition priming, picture naming, object identification, lexical access, bilingualism

Picture naming requires the execution of several distinct processes, including, minimally, identification of the pictured object, the retrieval of a word that names the object, and the overt articulation of the corresponding phonology. Existing models are in agreement about both the necessity of these three types of processes and the order of their initiation (Johnson, Paivio, & Clark, 1996). The extent to which these processes interact or overlap in time remains a subject of debate. Some models of picture naming are discrete stage models, in which these processes are completed serially (e.g., Levelt et al., 1991; Potter, So, Von Eckardt, & Feldman, 1984). Other models, often referred to as cascade models, have been developed to allow processes to overlap in time (e.g., Costa, Caramazza, & Sebastian-Galles, 2000; Humphreys, Riddoch, & Quinlan, 1988). Other models that could be applied to picture naming, such as critical path networks (Townsend & Schweickert, 1989), contain discrete stages that can be either serial or parallel.

The present study evaluates, through a series of bilingual and single-language repetition priming experiments, whether a discrete sequential model is adequate to account for changes in picture-naming performance following the practice of its components. These experiments factorially combined encoding tasks meant to selectively facilitate the component processes of picture naming.

The primary manipulations allowed us to estimate the unique contribution of each component and whether the components were independent. At the same time, we examined the nature of repetition priming, including the conditions of transfer, what processes contributed, what exactly was learned, and why response times decreased with practice. We assessed in a unique way whether bilingual picture naming involves access to amodal (language-general) concepts and to nontarget language representations. Finally, we examined effects of language proficiency and experimental practice on word production.

Picture naming is usually thought to include access to amodal concepts as the endpoint of the object identification process (e.g., Levetel et al., 1991; Potter et al., 1984; Theios & Amrhein, 1989; but see Johnson et al., 1996, for an argument against this position). Previous research has provided strong evidence that picture naming is concept mediated in monolingual individuals (Durso & Johnson, 1979; Potter & Faulconer, 1975; Smith & Magee, 1980) and in fluent bilingual individuals (Chen & Leung, 1989; Francis, Augustini, & Sáenz, 2003; Potter et al., 1984). Also supporting concept mediation of picture naming are neuroimaging studies showing that picture naming is associated with cortical activation in both the ventral “what” visual stream and areas associated with speech production (e.g., Martin, Wiggs, Ungerleider, & Haxby, 1996; van Turenout, Białamowicz, & Martin, 2003). The present investigation focuses on two subsets of the processes required for picture naming: (a) object identification and (b) word production. Object identification includes perceptual processes and retrieval of the concept. Word production involves selecting an appropriate word on the basis of the concept, accessing its phonology, and articulating the overt verbal response. In this study, these processes are linked to memory through item-specific learning as it is exhibited in repetition priming.

Processes in Object Identification

Research on visual perception has identified several steps necessary for object identification to occur (e.g., Biederman, 1987).
Object identification begins with low-level perceptual processes to filter stimuli on the basis of spatial frequency and orientation and segment edges and vertices. Once sufficient information is extracted, an abstracted mental representation, or structural description, forms to represent the structural properties of the object. Finally, that representation is matched against representations stored in long-term memory; when the match is found, the concept is accessed.

Several questions about object identification were of interest in the present study. First was the question of whether these processes can be treated as discrete sequential stages. Second was whether exposure to pictures of real objects induce automatic covert naming. Third was whether any of these processes generalize across different exemplars of the same object concept (elaborated in the section on repetition priming). Finally, we asked not only whether these processes would exhibit item-specific learning with repetition, but also whether such learning depends on processes that occur after identification has occurred.

Processes in Word Production

Whereas object identification research addresses the processes leading from the presentation of the stimulus to conceptual access, word production research evaluates the processes that occur after the concept has been accessed. Several additional processes must transpire to result in a spoken word. Models of word production typically include the processes of accessing a lemma (syntactic form), accessing the corresponding phonological word form (lexeme), selecting the phonemes to be sequenced (in preparation for articulation), and overt articulation of the response (Dell & O’Seaghdha, 1992; Levelt, Roelofs, & Meyer, 1999).

We examined several issues in bilingual word production through the inclusion of bilingual participants and materials as well as word translation as an encoding task. First, in the bilingual literature, there has been a long-standing debate about the processing routes used for bilingual picture naming and word translation (e.g., Chen & Leung, 1989; de Groot & Poot, 1997; Potter et al., 1984; Sholl, Sankaranarayanan, & Kroll, 1995). The present experiments addressed whether these tasks were concept mediated or word mediated. Second, recent research has focused on the extent to which the unintended (nontarget) language is accessed during comprehension or production of the other language. Several recent results have suggested that lexical access in bilingual picture naming is nonselective with respect to language, particularly for naming in the nondominant language. Incidental activation of the nontarget language appeared to have consequences for immediate processing of both the target and the nontarget language (e.g., Colomé, 2001; Costa, Miozzo, & Caramazza, 1999). In the present research, we tested whether there are long-term processing consequences. We also examined changes in language production on the basis of learning that occurs as a result of experimental exposures and previous bilingual experience.

Implicit Memory and Learning Processes in Repetition Priming

Decomposition of the mechanisms underlying memory performance has been a major focus of cognitive, neuropsychological, and neuroscientific research on memory. Dissociation methodology has been used to build the case that different types of memory rely on distinct memory subsystems or on distinct sets of cognitive processes. Given that dissociations among various implicit memory tasks have revealed that implicit memory has multiple cognitive and neural bases (Gabrieli, 1998; Schacter & Buckner, 1998), we may also ask whether multiple cognitive mechanisms of facilitation operate within a single repetition-priming paradigm.

Memory research has shown that response times (RTs) for naming repeated pictures decrease with successive repetitions, exhibiting a typical negatively accelerated learning curve across several practice trials (Bartram, 1974; Gollan, Montoya, Fennema-Notestine, & Morris, 2005). A similar function was observed in decreased neural responses across successive repetitions of a picture stimulus (Sayres & Grill-Spector, 2006; van Turrenout et al., 2003). Typically, the picture-naming task has been used to study learning that resulted from a single experimental exposure; that is, repetition priming, measured as the RT difference between new and repeated items at test (Durso & Johnson, 1979). Repetition of picture stimuli was also associated with reductions in neural activity as measured through single-cell recording, event-related potential, and functional MRI (Grill-Spector, Henson, & Martin, 2006). Facilitation for repeated pictures was durable over delays of several weeks (e.g., Cave, 1997; Mitchell & Brown, 1988; Wiggs, Weisberg, & Martin, 2006), indicating that repetition priming reflects sustained learning rather than temporary activation. The corresponding reduction in cortical activation also lasted for at least 3 days (van Turrenout et al., 2003). The preservation of RT priming effects for picture naming in global amnesia even at a 1-week interval (Cave & Squire, 1992) indicates that it does not require support from explicit memory. Thus, repetition priming in picture naming is considered to be a purely implicit memory phenomenon, a nonhippocampal form of memory.

The experiments to follow examined why RT decreases when items are repeated from encoding to test, that is, where exactly the time is saved to produce a shorter RT. Predictions in this study built on the idea that speeded responses arise because the component processes are executed more quickly. However, we also evaluated the predictive value of an alternative explanation based on a qualitative change in processing route or neural circuitry (Raichle et al., 1994; van Turrenout et al., 2003). A second goal was to operationally define repetition; that is, to determine what exactly must be repeated to elicit long-term facilitation. The learning exhibited in repeated picture naming provided a way to examine how object identification and word production improve with different types of practice and whether these sets of processes are independent.

Repetition Priming in Object Identification Processes

Any process required for either object identification or word production that is not overlearned is a potential locus for facilitation when picture naming is repeated. The contribution of object identification processes to repetition priming in picture naming has been demonstrated using encoding tasks that require accessing conceptual information about pictures. For example, decisions about the animacy, weight, natural or manufactured origin, or category membership of a pictured object facilitated later naming relative to new items (Carroll, Byrne, & Kirsner, 1985; Vaidya et
al., 1998). Classifying a picture as new in a recognition test also facilitated later naming (Lachman, Lachman, Thronesbery, & Sala, 1980). In bilingual individuals, prior naming of pictures in one language facilitated naming the same pictures in the other language relative to new items (Francis et al., 2003; Francis & Sáenz, 2007; Hernandez & Reyes, 2002). Similarly, repetition decreased activation of cortical regions associated with object identification in both picture naming (van Turenout et al., 2003) and semantic classification tasks (Sayres & Grill-Spector, 2006; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997).

In a complementary fashion, changes in visual input from encoding to test can reduce priming relative to an identical repetition, but it depends on the level of visual processing involved. Early visual processing does not appear to contribute to item-specific repetition effects. Changes in left–right reflection (Stankiewicz, Hummel, & Cooper, 1998), color and shading (Cave, Bost, & Cobb, 1996; Cave & Squire, 1992), and size (Biederman & Cooper, 1992; Cave & Squire, 1992) did not reduce long-term priming. Consistent with these behavioral effects, early visual areas (V1 and V2) did not exhibit reductions in activation with repeated pictures in naming (van Turenout et al., 2003) or semantic classification (Sayres & Grill-Spector, 2006; Wagner et al., 1997). These processes may be overlearned, as they occur in perception of all objects.

Changes in visual input at a higher level did reduce priming. Changing viewpoint from encoding to test reduced priming relative to identical repetition, and changing the exemplar reduced priming relative to simply changing the viewpoint (Bartram, 1974). Relative to an identical repetition, changing the exemplar of pictured object from encoding to test reduced RT priming in picture naming (Bartram, 1974; Cave et al., 1996; Cave & Squire, 1992) and reduced neural priming in semantic classification of pictures (Koutstaal et al., 2001). Positive evidence for exemplar-specific priming was the finding that briefly flashed pictures were more likely to be identified when they were repeated exactly after several minutes but not when the exemplar changed (Bar & Biederman, 1998), with identical repetition also eliciting neural priming (Badgaiyan, 2000). These findings indicate that there is an exemplar-specific component to long-term priming in object identification.

Whether there is also an exemplar-general component to long-term priming in object identification has heretofore been unknown. In this study, we provide the first behavioral evidence for object identification priming that generalizes across different exemplars of the same basic-level object category. In previous studies, exemplar-general object identification priming has never been isolated because priming that transfers across exemplars in semantic classification and picture naming could be due to repetition of decision or word production processes rather than identification processes per se. The same interpretation issue applies to “neural priming” in anterior inferotemporal and left inferior frontal cortex that transfers across exemplars in semantic classification (Koutstaal et al., 2001). The use of bilingual materials allows for the isolation and testing of exemplar-general identification processes by changing both the exemplar and the response language (Experiment 3).

Repetition Priming in Word Production Processes

The contribution of word production processes to repetition priming in picture naming is evident in studies that incorporated encoding tasks that required selecting and/or articulating the name without presentation of the target picture. Picture naming was facilitated by generating a picture’s name in response to a definition (Lee & Williams, 2001; Monsell, Matthews, & Miller, 1992; Wheeldon & Monsell, 1992) or as a translation response (Francis et al., 2003; Francis & Sáenz, 2007). Naming a different exemplar of an object at encoding also elicited facilitation (e.g., Bartram, 1974; Biederman & Cooper, 1991; Cave & Squire, 1992; Durso & Johnson, 1979), but it is unknown how much of this priming was based on exemplar-general object identification and how much was based on repeated word production. Further evidence for a word production component is that repeated picture naming decreased cortical activation in language production regions (van Turenout et al., 2003). The present experiments addressed item-specific facilitation in word production in the context of picture naming and in how that facilitation is moderated by language proficiency, with the goal of identifying the mechanisms involved.

Although these previous studies provided evidence that both identification and production processes contributed to repetition priming in picture naming, they did not include the conditions necessary to show definitively that different processes were facilitated by the different encoding tasks. With a retention interval manipulation, identification and production components of repetition priming in picture naming were dissociated, such that from a 10-min to a 1-week retention interval, the production component of priming decreased 39%, but the identification component of priming did not decrease detectably (Francis & Sáenz, 2007). The identification component of priming must therefore not involve fast-decaying processes, but the production component does, indicating that some different processing mechanisms are involved. However, strictly speaking, this dissociation did not tell us whether the production component also contains slow-decaying processes or whether the processes contributing to facilitation of identification and production are independent and additive. The additivity assumption was not directly tested. Similarly, identification and production processes were differentially affected by a manipulation of response language (Francis et al., 2003; Francis & Sáenz, 2007).

The present study used an additive factors approach to test whether a sequential model with independent processing components adequately explains the patterns of repetition priming for picture naming or whether such a model must be rejected in favor of one that incorporates overlap or dependence parameters. The experiments decomposed implicit memory processes within a single memory paradigm, with a focus on the involvement of identification and production processes in repetition priming for picture naming.

Transfer-Appropriate Processing Logic

Predictions in this study were derived from an explicit quantitative model based on the principle of transfer-appropriate processing (Morris, Bransford, & Franks, 1977; Roediger & Blaxton, 1987), the idea that the degree of transfer or priming from encoding to test depends on the degree to which the cognitive processes involved in encoding and test tasks overlap. Because transfer-appropriate processing is a principle rather than an explicit model (Franks, Bilbrey, Lien, & McNamara, 2000), the manner in which it is interpreted and applied varies considerably across researchers.
in terms of what processes are considered and how hypotheses about transfer-appropriate effects are derived. One criticism of the transfer-appropriate processing principle is that it has not been specified sufficiently for it to be testable (Gorfein & Bubka, 1997).

In the present study, we derived predictions about repetition priming from a specific interpretation of transfer-appropriate processing in which common processes between encoding and test tasks are the 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 approach to transfer-appropriate processing is similar to those used by previous researchers to reason about repetition priming (Monsell et al., 1992; Sholl et al., 1995). However, we have taken this logic a few steps further by making the bases for deriving predictions more explicit.

This version of transfer-appropriate processing differs from several other transfer-appropriate processing explanations in the repetition priming literature, such as the match between data-driven and conceptually driven processing at study and test (e.g., Roediger & Blaxton, 1987) or the match between domains of semantic representation accessed at study and test (e.g., Thompson-Schill & Gabrieli, 1999). Although the different approaches lead to many similar predictions, the present experiments also have conditions that could potentially discriminate among the different approaches.

Across our experiments, we chose encoding tasks on the basis of the processes they share with picture naming. Processes were defined in terms of start- and endpoints and the path taken between them (as in Theios & Amrhein, 1989; Townsend & Schweikert, 1989), all of which had to match for two processes to be considered equivalent. Only the path was assumed to take time and exhibit priming. Each experiment in this study included a set of repetition conditions meant to facilitate object identification, word production, or a combination of these processes. The use of bilingual materials allowed the application of two labels to the same concept, which in turn facilitated isolation and selective influence of identification and production processes. Evidence that translation equivalents for concrete nouns access the same conceptual representation is well established in the cognitive bilingual literature (for reviews, see Francis, 1999, 2005).

The simplicity of the task analysis for picture naming, along with the straightforward interpretation of transfer-appropriate processing, allowed for the critical hypotheses to be expressed and quantified in a simple linear model. The second column of Table 1 is a listing of the encoding task–test task combinations, or conditions, tested in each of the six experiments. With the exception of Conditions 27 and 28 from Experiment 4, the final test task was always picture naming in the dominant or nondominant language. (The encoding tasks involved in the various conditions are illustrated in Figure 1). The next four columns summarize the task analysis by indicating the processes shared by the encoding and test tasks in each condition. The priming contributions of the component processes in each condition were summarized in a linear expression. For example, in the second condition listed, when the encoding task is translation from the nondominant language (L2) to the dominant language (L1) and the test task is picture naming in L1, word production processes in L1 are repeated, and the priming contribution is indicated by the term \( w_{1A} \).

The shared processes were hypothesized to be the basis of priming in all conditions and are the basis on which predictions about priming were made. (We return to the final two columns of Table 1 in the quantitative model section.)

The Present Study

We designed the present series of experiments to decompose implicit memory processes within a single memory paradigm using additive factors logic and to test the explanatory value of a theoretical model on the basis of the transfer-appropriate processing principle. Each experiment included encoding conditions meant to selectively facilitate or reduce facilitation in object identification, word production, or both. These encoding manipulations in picture identification or word production were combined factoredly, 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. 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.

With respect to independence of processes, 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. In the first situation, the two encoding tasks are sequential and together involve all processes in the test task. In the second, the two encoding tasks are sequential but do not cover all processes in the test task. In the third, the two encoding tasks overlap in time or have some processes in common.

As illustrated in the first two situations, with nonoverlapping tasks, facilitation in the combined condition is expected to be equal to the sum of the two individual effects. In contrast, with overlapping processes, the sum of the individual effects is greater than that of the identical repetition condition, and these two values constitute the upper limit and lower limit, respectively, for facilitation in the combined condition. If practicing a process a second time before final repetition confers no additional benefit, then the combined effect would be equal to the identical repetition effect. If practicing a second time gives as much benefit as the first, the combined effect would equal the sum of the individual effects. However, across many domains, it is known that the effects of practice are negatively accelerated, such that each additional practice trial confers less benefit than the preceding trial (power law of practice; Newell & Rosenbloom, 1981). Therefore, facilitation in the combined condition is expected to be greater than the identical repetition effect but less than the sum of the two individual effects. Under no circumstance was a combined effect expected to exceed the sum of its parts in superadditive interaction; such a pattern would contradict the well-established learning function.
Implications of this transfer-appropriate processing approach were tested in six experiments. Experiments 1, 2, and 3 were bilingual experiments, and Experiments 4, 5A, and 5B were single-language experiments. The use of bilingual materials in Experiments 1, 2, and 3 allowed the application of two labels to the same concept, which facilitated isolation and selective influence of identification and production processes. This method also provided two tests of independence of influences in each experiment, one in each language of the bilingual participants. Experiments 4, 5A, and 5B allowed the estimation of identification and production processes in English- and Spanish-speaking monolingual participants.

Experiment 1

The purpose of Experiment 1 was to selectively influence object identification and word production processes in picture naming. As...
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Illustrated in Figure 3, the task meant to selectively facilitate object identification was naming the picture in a different language than the final naming language (e.g., naming a picture of an apple in Spanish at encoding and naming the same picture in English at test). As indicated earlier, priming based on prior picture naming in a different language has been established in previous studies.

The task meant to facilitate word production was translating a word into the same language as the final naming task (e.g., translating caballo to horse at encoding and naming a picture of a horse in English at test). The use of this encoding task entails the assumption that translation is concept mediated, that is, that it requires accessing the shared concept before retrieving the corresponding word in the other language. Although there is some dispute about translation processes in late or nonfluent bilingual individuals, previous research has converged to support the conclusion that translation in both directions is concept mediated for fluent early bilingual individuals (e.g., de Groot & Poot, 1997; Francis et al., 2003; Francis & Gallard, 2005; La Heij, Hooglander, Kerling, & van der Velden, 1996). On the basis of these considerations, we assumed that translation was concept mediated in both directions, but Experiments 1 and 2 also provide tests of this assumption. As explained in the introduction, previous studies demonstrated priming of picture naming on the basis of prior translation. Conversely, picture naming also primes later translation (Francis et al., 2003; Sholl et al., 1995). Both types of priming

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**Figure 1.** Examples of encoding tasks for key experimental conditions when the test task is naming pictures in English.

<table>
<thead>
<tr>
<th>Final Naming Task</th>
<th>Stimulus</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picture naming in English</td>
<td><img src="apple.png" alt="image" /></td>
<td>&quot;apple&quot;</td>
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<tr>
<td>Encoding Task</td>
<td></td>
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<tr>
<td>Same-Language Naming</td>
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<tr>
<td>(Same Exemplar)</td>
<td><img src="apple.png" alt="image" /></td>
<td>&quot;apple&quot;</td>
</tr>
<tr>
<td>Different-Language Naming</td>
<td></td>
<td></td>
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<tr>
<td>(Same Exemplar)</td>
<td><img src="manzana.png" alt="image" /></td>
<td>&quot;manzana&quot;</td>
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<tr>
<td>Translation to Same Language</td>
<td><img src="manzana.png" alt="image" /></td>
<td>&quot;apple&quot;</td>
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<tr>
<td>Different-Exemplar Naming</td>
<td><img src="apple.png" alt="image" /></td>
<td>&quot;apple&quot;</td>
</tr>
<tr>
<td>in Same Language</td>
<td><img src="manzana.png" alt="image" /></td>
<td>&quot;manzana&quot;</td>
</tr>
<tr>
<td>Same-Exemplar Classification</td>
<td><img src="natural.png" alt="image" /></td>
<td>&lt;natural&gt;</td>
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<tr>
<td>Different-Exemplar Classification</td>
<td><img src="natural.png" alt="image" /></td>
<td>&lt;natural&gt;</td>
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</tbody>
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**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 performed on the same item before the final test task. Expectations of facilitation for these three conditions are given for three situations: (a) Processes of Tasks X and Y do not overlap, but together they involve all processes of the test task; (b) processes of Tasks X and Y do not overlap, and together they do not involve all processes of the test task; and (c) processes of Tasks X and Y overlap and together involve all processes of the test task.

The priming effects from these two tasks summed to approximately the priming effect obtained with identical repetition, both immediately and after a 1-week delay (Francis et al., 2003; Francis & Sàenz, 2007), a pattern that suggests process independence. However, Experiments 1 and 2 provide a more direct test by including a combined condition in which a target picture is both named in the nontarget language and has its name produced as a translation response. If the processes are independent, the effects

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**Nonoverlapping Processes; Complete**

- **Encoding Task X**
  - A
- **Encoding Task Y**
  - B
- **Test Task**
  - C

<table>
<thead>
<tr>
<th>Nonoverlapping Processes; Incomplete</th>
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<tbody>
<tr>
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<tr>
<td>A</td>
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<td>B</td>
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<td><strong>Test Task</strong></td>
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<th>Overlapping Processes; Complete</th>
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<tr>
<td><strong>Encoding Task X</strong></td>
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<td>A</td>
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<td><strong>Encoding Task Y</strong></td>
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<tr>
<td><strong>Test Task</strong></td>
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<td>C</td>
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**Figure 3.** Examples of encoding tasks for key experimental conditions when the test task is naming pictures in a different language.
obtained individually for these two encoding tasks will sum to the effect for the combined condition; nonindependence would lead to a subadditive interaction, such that the combined effect will be less than the sum of individual effects. This study was conducted with unbalanced bilingual participants with final picture naming in both their dominant and nondominant languages to provide two independent tests, one with a smaller word production component and one with a larger one.

**Method**

**Participants.** Forty-eight self-identified Spanish–English bilinguals (34 women and 14 men) participated. All were undergraduate or graduate students at the University of California, Los Angeles, who participated for course research credit or as unpaid volunteers. They ranged in age from 17 to 39 (\(Mdn = 19\); 3 did not report their age). All but 2 (1 Asian American and 1 African American) reported their ethnicity as Latino. Of the participants for whom information was available, 2% had learned English first, 80% had learned Spanish first, and 18% had learned both languages simultaneously from early childhood; 81% indicated that English was their dominant language, and 19% indicated that Spanish was their dominant language. Thus, in this sample, most of the students were more fluent in their second language than in their first language. Five other students completed the procedures but were replaced because of poor performance due to insufficient Spanish proficiency.

**Apparatus.** Stimuli were presented on a Macintosh Classic computer monitor. The sequence and timing of presentation was programmed using Psychlab software (Bub & Gum, 1990). Vocal naming RTs were collected by means of a voice relay (Grason SC Voice Relay adapted for connection via the mouse port, converting each response to a mouse click signal).

**Design.** The experimental manipulations constituted a 6 (encoding condition) × 2 (final naming language) within-subjects design. The six encoding conditions were defined by the relationship of the encoding task to the test task of picture naming. Four of these conditions were critical for the additive factors methodology and test of independence. These were the items that were not presented at encoding in any form, pictures named in a different language at encoding, items whose names in a different language were presented and translated to the target language at encoding, and items having undergone both tasks on separate trials during encoding. These four conditions along with response language constitute a 2 (item previously named in a different language or not) × 2 (item previously translated to target language or not) × 2 (final naming language) factorial structure for testing the independence of the selective influences of these encoding manipulations on object identification and word production processes. The fifth encoding condition was identical repetition, pictures named in the same language at encoding and test, which provided an anchor for scaling the magnitudes of the other priming effects. A sixth encoding condition not central to the hypothesis of independence consisted of items whose names were presented in the target language at encoding and translated to the nontarget language.

**Materials.** We assembled a set of items suitable for both picture naming and translation. The picture stimuli came from the Snodgrass and Vanderwart (1980) set. These stimuli were further narrowed down on the basis of four criteria: (a) high name agreement in English, (b) high name agreement in Spanish, (c) relatively unambiguous word translation, and (d) relatively easy vocabulary items. Using these criteria, we selected a set of 108 items. The median frequency of the English names was 23 per million (Kucera & Francis, 1967). The mean letter lengths of the names were 5.0 in English and 5.8 in Spanish. Name agreement means for these pictures in English- and Spanish-speaking samples in the El Paso–Juárez region were 93.6% and 91.4%, respectively (Goggin, Estrada, & Villarreal, 1994). The stimulus set was randomly divided into 12 sets of nine items, each set corresponding to one

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**Figure 3.** Logic of Experiments 1 and 2. Picture naming in the dominant language (L1) and picture naming in the nondominant language (L2) share object identification processes. Picture naming in the nondominant language and translation to the nondominant language share word production processes. Quotation marks indicate overt responses.
experimental condition. The sets were rotated through the different conditions using a Latin square to control for specific item effects.

Procedure. A bilingual experimenter tested participants individually in sessions lasting approximately 30 min. Instructions for each task were given in the assigned response language for that task. The encoding phase had four blocks of trials, corresponding to the four experimental tasks: English picture naming, Spanish picture naming, translating words from Spanish to English, and translating words from English to Spanish. Each trial block consisted of 3 filler trials and 27 experimental trials. On each trial, a 250-ms warning signal and 250-ms blank screen preceded the stimulus item. The stimulus remained on the screen until the voice relay registered a response, and after a 500-ms intertrial interval, the next warning signal appeared. Participants were to respond as quickly and accurately as possible. The experimenter noted unexpected responses and voice-relay misfires on a preprinted worksheet containing the sequence of expected responses. The test phase had two blocks of trials, English picture naming and Spanish picture naming, each with 54 trials. Language and task orders were counterbalanced across participants. At the end of the session, participants completed a language background questionnaire and were debriefed.

Results

Analyses focused on valid RTs for test-phase trials with correct naming responses. In all experiments, we retained unexpected but appropriate naming responses for analysis when the response was consistent across repetitions. After removing error trials ($M = 7.1\%$, $SD = 3.8\%$), mistimed trials (1.1%), trials with stimulus errors (0.2%), spoiled trials (10.8%), and remaining trials with RTs greater than 5 s (1.1%), we obtained mean test-phase RTs in each condition for each participant. (Spoiled trials were those that had correct responses, but the intended encoding condition for the item was compromised because the encoding-phase response was unacceptable, inconsistent with the test-phase response, or had a machine timing error or the expected response was produced in error for an earlier item.) After exclusions, the average number of trials remaining for each condition was 7.2 (79.6%). The means of the remaining valid RTs for each participant in each condition were entered into the main analyses.

Nouns in the English language with frequencies of at least 1 per million were coded to estimate the number of possible items for use in these experiments. This analysis identified nonredundant concrete nouns corresponding to visual object concepts that would be (a) identifiable and unambiguous in a black-and-white line drawing, (b) not too difficult to be in bilingual vocabulary, (c) unambiguous in translation to and from Spanish, and (d) not identically spelled in Spanish or differing only by a diacritical mark. Approximately 550 items fit these criteria. The experiments reported here used about 50% of those items, with the exception of Experiment 1, which had less fluent bilingual participants and a more strict difficulty threshold. When the population of potential items is exhausted, the need to generalize statistically across items is obviated (Clark, 1973). By that same logic, when a large proportion of the item pool is exhausted, it is likewise inappropriate to use statistical generalization across items, and for this reason, we do not report analyses with items as a random factor for any of the present experiments.

Because language proficiency affects RTs, error rates, and priming, we based analyses on the dominant and nondominant language for each participant. The dominant language of each participant was defined by the faster picture-naming language in the encoding phase. Encoding-phase RTs and error rates are given in Table 2. Test-phase RTs and error rates are given in Table 3, and priming effects are illustrated in Figure 4. Priming scores were obtained by subtracting the RTs of the studied conditions from the RTs of the new item conditions. Repetition priming was reliable in every cell ($p < .05$) except for when pictures were named in the dominant language at encoding and the nondominant language at test ($p = .29$), a cell with high variability.

We submitted RTs for this critical factorial combination of encoding tasks to a 2 (item previously named in a different language or not) × 2 (final naming language) repeated measures ANOVA. A main effect of prior naming in a different language indicated that practice of object identification processes facilitates picture naming, $F(1, 47) = 7.096$, $MSE = 67,361$, $p = .011$. A main effect of prior translation to the target language indicated that practice of word production processes facilitates picture naming, $F(1, 47) = 54,992$, $MSE = 53,157$, $p < .001$. These effects did not interact, suggesting that they make independent contributions to priming ($F < 1$). An examination of the priming scores clarifies that the magnitude of facilitation for items previously both translated to the target language and named in the nontarget language (245 ms) was indistinguishable from the sum of the magnitudes of facilitation elicited by each of those tasks alone (72 ms + 175 ms = 247 ms). This effect is also comparable to the priming effect observed in the identical repetition condition (244 ms).

Responses were faster overall in the dominant language, $F(1, 47) = 34.77$, $MSE = 177,437$, $p < .001$. Priming based on previous naming in a different language did not differ across languages ($F < 1$). However, priming based on previous translation to the target language was stronger when final naming responses were given in the nondominant language, $F(1, 47) = 10,926$, $MSE = 65,490$, $p = .002$, showing that the contribution of word production processes depended on language proficiency. The additive pattern of priming was observed in both languages, and the languages did not differ in that respect, as indicated by a nonsignificant three-way interaction ($F < 1$).

Discussion

Picture naming was facilitated by prior picture naming in a different language and by prior translation to the target-naming language, indicating that both object identification and word production processes were facilitated. These two effects were additive, and the priming obtained after the two sets of processes were practiced on separate encoding trials (combined condition) was equivalent to the priming obtained following one identical repetition, suggesting that independent processes underlie the two priming effects. This pattern was observed for both the dominant language with its shorter RTs and smaller priming effects and the nondominant language with its longer RTs and larger priming effects.
Experiment 2 was a conceptual replication of Experiment 1, but with the primary goal being to maximize the power to detect deviations from linear independence. To accomplish this, we tested the same hypotheses with a larger sample of more proficient bilingual participants. Because the bilingual participants were more proficient, we were able to include more difficult items, increasing the number of items per cell from 9 to 32 to yield more precise estimates of each participant’s performance.

Method

Participants. Eighty self-identified Spanish–English bilinguals (50 women and 30 men) participated. All were undergraduate or graduate students at the University of Texas at El Paso, who participated for a course research requirement, as unpaid volunteers, or for $5 compensation. The participants ranged in age from 17 to 55 (\(Mdn = 19\)). The student participants lived in the U.S.–Mexico border region of El Paso, Texas, and Juárez, Chihuahua, and therefore had regular exposure to both English and Spanish. In a prescreening measure, all had selected one of the middle three points on a 9-point relative proficiency scale. On the basis of self-ratings of relative proficiency, 60% were classified as English dominant, and 40% were classified as Spanish dominant; 85% of the students had learned Spanish first, 4% had learned English first, and 10% had learned both languages simultaneously from early childhood (1 participant did not report this information). Eleven other students completed the procedure but were

### Table 2

<table>
<thead>
<tr>
<th>Experiment and encoding task</th>
<th>English RT (ms)</th>
<th>English ER (%)</th>
<th>Spanish RT (ms)</th>
<th>Spanish ER (%)</th>
<th>Dominant RT (ms)</th>
<th>Dominant ER (%)</th>
<th>Nondominant RT (ms)</th>
<th>Nondominant ER (%)</th>
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<td>13.6</td>
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<td>6.6</td>
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<td>1,418</td>
<td>12.9</td>
<td>1,375</td>
<td>8.9</td>
<td>1,419</td>
<td>13.0</td>
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<td>1,266</td>
<td>15.0</td>
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\(^a\)Stimuli that were also used in Experiment 1

### Table 3

<table>
<thead>
<tr>
<th>Experiment and encoding task</th>
<th>RT (ms)</th>
<th>Error rate (%)</th>
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<tr>
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<td></td>
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<tr>
<td>PN different language</td>
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<td>1,462</td>
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<tr>
<td>TR same language</td>
<td>1,102</td>
<td>1,266</td>
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<td>PN different language &amp; TR same language</td>
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<td>1,200</td>
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<td>PN same language</td>
<td>1,019</td>
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<tr>
<td>Experiment 2</td>
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<td>Not presented</td>
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<tr>
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<td>TR same language</td>
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<td>1,092</td>
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<tr>
<td>PN same language</td>
<td>1,044</td>
<td>1,058</td>
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</table>

\(L1 =\) dominant language; \(L2 =\) nondominant language; \(PN =\) picture naming; \(TR =\) translation
replaced because of error rates greater than 50% in either English or Spanish. All reported Hispanic ethnicity. (The ethnicity term is changed here because in response to an open-ended question, Latino was the ethnicity term generated by the Los Angeles participants, and Hispanic was the ethnicity term generated by the El Paso participants.)

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 and materials. The design was the same as in Experiment 1, except that the nonessential encoding condition of translating from the target language to the nontarget language was eliminated. Using the same criteria as in Experiment 1 but allowing greater difficulty, a set of 320 items was selected from several picture sets, primarily the Pictures Please library (Abbate, 1984). The median frequency of the English names was 13 per million (Küçürek & Francis, 1967); thus, this stimulus set contained items with less frequent names than the set used in Experiment 1. The mean letter lengths of the names were 5.7 in English and 6.3 in Spanish. These items were randomly divided into 10 sets of 32 items, and the sets were rotated through the 10 experimental conditions across participants using a Latin square to control for specific item effects.

Procedure. The procedure and controls for task and language order were the same as Experiment 1 except for the following aspects. In the encoding phase, each block of trials began with 4 filler trials, picture-naming blocks had 96 experimental trials, and translation blocks had 64. On each trial, the stimulus appeared in the center of the screen, remained on the screen until a vocal response was registered, and then the screen was blank for a 1,000-ms interval before the next trial began. In the test phase, there were two blocks of 160 picture-naming trials (block randomized), one in each language, with a short break halfway through each block.

Results

Out of a total of 320 test-phase trials, 5 trials (1.6%) were removed because of stimulus list errors. On average, 13.7% (SD = 5.1%) were removed as naming or translation response errors (including ‘don’t know’ responses), 0.9% were removed as machine timing errors, and 11.9% were removed as spoiled trials. Items with RTs greater than 5,000 ms, less than 200 ms, or more than 2 standard deviations from the mean were removed as outliers, which resulted in the exclusion of 4.3% of the trials. (The procedure for removing outliers was changed for this and subsequent studies because there were more items per condition, giving more accurate distribution information.) Thus, on average, we retained 67.6% of the test-phase trials for the RT analysis, which left a mean of 21.6 items per condition per participant.

English and Spanish data were recoded according to the dominant and nondominant language obtained from self-ratings of relative proficiency. Encoding-phase RTs and error rates are given in Table 2. Test-phase picture-naming RTs and error rates are shown in Table 3, and priming scores are shown in Figure 4. Priming scores were statistically reliable in every cell (p < .02).

We submitted RTs for the critical factorial combination of encoding tasks to a 2 (item previously named in a different language or not) × 2 (item previously translated to the target language or not) × 2 (language of final naming) repeated measures ANOVA. A main effect of prior naming in a different language indicated that practice of object identification processes facilitates picture naming, F(1, 79) = 35.43, MSE = 24,224, p < .001. A main effect of prior translation to the target language indicated that practice of word production processes facilitates picture naming, F(1, 79) = 215.81, MSE = 24,219, p < .001. These two effects did not interact, suggesting that they make independent contributions to priming (F < 1). The magnitude of facilitation for items previously both translated to the target language and named in the nontarget language (254 ms) was close to the sum of the magnitudes of facilitation after each of those tasks alone (79 ms + 186 ms = 265 ms). These values are also comparable to the identical
repetition condition effect, which yielded 273 ms of facilitation. Overall, responses were faster in the dominant language than in the nondominant language, $F(1, 79) = 4.60, MSE = 88,034, p = .035$, but language did not interact with the encoding condition effects ($Fs < 1$).

**Discussion**

As in Experiment 1, picture naming was facilitated both by prior naming in a different language and by prior translation to the target language. These effects were additive in both languages, and the combined condition effects were equivalent to the identical repetition effects. This pattern was consistent with the expectations for independent contributions of object identification and word production processes. Because there were no effects of language on priming, we can consider that with the data aggregated across languages, there were 64 observations per condition for 80 participants and thus a total of 5,120 trials per condition. Even with this large data set, there was no evidence of a substantial deviation from additivity.

In Experiments 1 and 2, the combined condition meant to facilitate both object identification and word production was the only condition in which a concept was presented twice in the encoding phase before final picture naming. We were concerned that the conceptual repetition in itself could influence priming. To alleviate this concern, we designed Experiment 3 using a different strategy so that the combined selective influence could be implemented in a single encoding-phase trial. It was also meant to test whether the additive effects observed were specific to the set of manipulations used in Experiments 1 and 2.

**Experiment 3**

In Experiment 3, we assessed the independence of selective influences on object identification and word production using a different method. The new method incorporated three new features: (a) The task and corresponding instructions (except for language) were constant throughout the experiment; (b) combined condition items only had to be presented once in the encoding phase; therefore, effects of combining the selective influences could not be attributed simply to multiple presentations; and (c) the conditions were conceptualized in terms of reducing priming relative to the identical case rather than eliciting priming relative to nonpresented items.

For Experiment 3, the logic for testing independent influences was reversed. We expected, on the basis of previous studies, that changing the exemplar used from encoding to test would reduce priming relative to identical repetition (e.g., Cave et al., 1996) by removing some components of the object identification contribution to the identical repetition priming effect. However, even different exemplars of the same object tend to have similar structures, so we expected some higher level object identification processes to be shared even by different exemplars of an object. However, there has been no previous demonstration of exemplar–general object identification priming. We expected that changing the language from encoding to test would reduce priming relative to the identical replication case as in Experiments 1 and 2 by removing the word production components of the identical repetition priming effect.

To assess the independence of these two reductions in priming, for some items the prior task was naming a different exemplar in the nontarget language. This condition was meant to remove or reduce both object identification and word production components; if these components are independent, the reduction in priming will equal the sum of the separate different exemplar and different language reductions. (Another way to conceptualize this independence is that changing the exemplar or changing the language will increase RT relative to an identical repetition, and changing both will increase the RT as much as the sum of their separate increases.) A new-item (not presented) condition was included for comparison with the condition in which different exemplars were presented for naming in different languages at encoding and test to determine whether changing both the exemplar and the language completely eliminates priming. Any remaining priming could be attributed to a component of object identification that generalizes across different exemplars of an object concept.

**Method**

**Participants.** Eighty self-identified Spanish–English bilingual participants (29 men and 51 women) were recruited from the same sources as in Experiment 2 and ranged in age from 17 to 48 ($Mdn = 20$). According to self-ratings of relative proficiency, 49% were classified as English dominant, and 51% were classified as Spanish dominant. According to the language background questionnaire, 87% had learned Spanish first, 4% had learned English first, and 9% had learned both languages simultaneously from early childhood. All but 1 participant reported Hispanic ethnicity. Seventeen other students completed the experimental protocol but were excluded and replaced because of insufficient proficiency in English or Spanish.

**Design and materials.** The experimental manipulations constituted a 5 (encoding condition) × 2 (final naming language) within-subjects design. Picture naming was the only task for encoding and test, and the conditions were defined by the relationship between the picture-naming tasks at encoding and test. The encoding conditions critical to the hypotheses of independence included naming the same exemplar in the same language, naming a different exemplar in the same language, naming the same exemplar in a different language, and naming a different exemplar in a different language. Along with response languages, these conditions were conceptualized as a 2 (same or different exemplar) × 2 (same or different naming language) × 2 (final response language) factorial structure. A fifth encoding condition included items that were not presented at encoding and were therefore new at test.

From the same sources used for Experiment 2, we selected 250 picture pairs. The median frequency of the English names was 15 per million (Kuczer & Francis, 1967). The two exemplars for each concept were randomly assigned to two sets, and the target set for final naming was counterbalanced across participants to control for potential picture set and typicality effects. Items were randomly assigned to 10 sets of 25 items that were rotated through conditions across participants using a Latin square to control for specific item effects.

**Procedure.** The apparatus, trial structure, and general procedure were the same as in Experiment 2. The encoding phase
DECOMPOSITION OF REPETITION PRIMING COMPONENTS

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consisted of an English picture-naming block and a Spanish picture-naming block, as did the final test phase. First-phase blocks consisted of 4 filler trials and 100 experimental trials, and test-phase blocks consisted of 125 experimental trials. In both phases, items from all relevant conditions were intermixed using block randomization. The order of English and Spanish blocks within encoding and final naming phases was counterbalanced across participants.

Results

Data were trimmed and processed in the same manner as in Experiment 2. Out of a total of 250 test-phase trials, 16.6% (SD = 5.8%) were removed as naming response errors, 0.9% were removed as machine timing errors, 12.3% were removed as spoiled trials, and 5.6% were removed as outliers. On average, 64.6% of the test-phase trials were retained for the RT analysis, about 16 items per condition per participant.

As in Experiment 2, English and Spanish data were recoded according to the self-reported language dominance of each participant. Encoding-phase RTs and error rates are given in Table 2. Test-phase RTs and error rates are shown in Table 4. Priming scores were obtained by subtracting repeated item RTs from new item RTs, and repeated items were named faster than new items in all four repetition conditions (p < .005). We obtained mean reductions in priming scores, or increases in RTs, by subtracting the mean RT of the identical repetition condition from the mean RT for the condition of interest. This is equivalent to subtracting the priming score for the condition of interest from the priming score of the identical repetition condition. Reductions in priming relative to identical naming repetition, shown in Figure 5, were significant in all three partial repetition conditions (p < .005).

We submitted priming scores to a 2 (same or different exemplar) × 2 (same or different naming language) × 2 (final naming language) repeated measures ANOVA. Changing the exemplar from encoding to test reduced priming, as indicated by a main effect of exemplar change, F(1, 79) = 15.56, MSE = 14,764, p < .001. Changing the response language from encoding to test also reduced priming, as indicated by the main effect of language change, F(1, 79) = 122.85, MSE = 24,677, p < .001. The effects of exemplar and language change did not interact, F(1, 79) = 1.40, MSE = 12,962, p = .240. Overall levels of priming were comparable for the dominant and nondominant languages (F < 1). The effect of changing the exemplar did not differ across final naming language, as indicated by a nonsignificant interaction (F < 1).

However, the effect of changing the language was more detrimental for final naming responses given in the nondominant language, F(1, 79) = 18.27, MSE = 17,272, p < .001. The three-way interaction was not reliable (F < 1). A planned comparison showed that relative to new items, changing both the exemplar and the language did not completely eliminate priming; 48 ms of priming remained, which was a statistically significant effect, t(79) = 3.150, p = .002.

Discussion

The reduction in priming due to changing only the exemplar was substantial, and it provides further evidence of the contribution of object identification processes to priming. Similarly, changing

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<th>Encoding condition</th>
<th>RT (ms)</th>
<th>Error rate (%)</th>
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Note. L1 = dominant language; L2 = nondominant language; PN = picture naming
only the response language substantially reduced priming as in Experiments 1 and 2, which indicates the contribution of word production processes. Changing both the exemplar presented and the response language from encoding to test reduced priming by approximately the sum of the effects of changing each alone. The results converged with those of Experiments 1 and 2, in that manipulations meant to selectively influence object identification and word production processes had noninteracting effects (although the numerical values did not fit as cleanly). However, these effects did not account for the entire facilitation effect observed with identical repetition, presumably because changing the exemplar did not completely eliminate shared object identification processes. This remaining facilitation demonstrates that exemplar–general object identification priming is possible.

Experiments 1, 2, and 3 all relied on the use of bilingual tasks, and therefore the participation of bilingual participants. Although it seems unlikely that repetition priming in bilingual individuals would be qualitatively different than repetition priming in monolingual individuals, it was of interest to attempt a decomposition that could be implemented in a single language. Also, in monolingual individuals, the variability in picture-naming RTs across individuals is less than with bilingual individuals. Experiments 4 and 5 are single-language experiments. Experiment 4 tests an assumption necessary for Experiment 5 in which a factorial manipulation of selective influences is implemented in single-language experiments.

Experiment 4

Experiments 4 and 5 were meant to extend the selective influence strategy to manipulations that could be implemented in a single language. Experiment 4 tested whether it would be appropriate to use semantic classification of pictures as a task to selectively prime object identification processes. Semantic classification of pictures must require some of the same perceptual processes as picture naming. However, classification does not require as precise a level of conceptual access as naming because structural features of objects are correlated with their semantic categories and superordinate-level conceptual access would be sufficient to make a classification, but basic-level access is needed for naming. Previous research has shown that semantic classification of pictures does not require access to the name, based on the fact that it is faster than picture naming (Durso & Johnson, 1979; Potter & Faulconer, 1975; Smith & Magee, 1980). However, it is unknown whether classification may nevertheless elicit incidental covert naming, which involves word production processes. If semantic classification elicits word retrieval, then it would be a bad candidate task to selectively facilitate object identification processes.

Repetition priming effects tend to be smaller for picture classification than for picture naming (Durso & Johnson, 1979; Gabrielli et al., 1999; Gollan et al., 2005). Previous research has shown that semantic classification of pictures facilitates later picture naming (e.g., Carroll et al., 1985) and that picture naming facilitates later semantic classification (Vaidya et al., 1998). However, the relative magnitudes of these two between-task effects have not been compared directly. Experiment 4 includes this comparison. Intentional covert naming has been shown to facilitate later overt picture naming as much as an identical overt naming repetition (Brown, Neblett, Jones, & Mitchell, 1991). Therefore, if semantic classification elicits covert naming, it will facilitate picture naming more than picture naming facilitates semantic classification. In contrast, if object identification processes are the only shared processes, then between-task priming will be symmetric. This experiment was conducted entirely in English with native English speakers.

Method

Participants. Participants were forty-eight University of Texas at El Paso students (28 women and 20 men), self-identified as speaking English as their dominant or only language. They ranged in age from 17 to 42 (Mdn = 22). According to self-reported ethnicity, 28 were Hispanic; 16, White non-Hispanic; 3, African American; and 1, Native American. All reported that they had learned English either as a native language or in early childhood.

Design and materials. The independent variables constituted a 3 (encoding condition) × 2 (test task) within-subjects design. The encoding conditions were same task, different task, or not presented. The test tasks were picture naming and picture classification. Picture stimuli were selected from the same sources as for the other experiments. Each picture had to be unambiguous with respect to the natural or manufactured classification. Of the 288 pictures selected, 102 were natural and 186 were manufactured. The median frequency of the English names was 15 per million (Kucera & Francis, 1967). These pictures were randomly assigned to six sets of 48, with 17 natural and 31 manufactured items in each set. The six item sets were rotated through the six experimental conditions across participants using a Latin square to control for specific item effects. The two sets of items assigned to each encoding-phase task were randomly intermixed with the restriction that no more than 3 items with the same natural or manufactured classification and no more than 4 items from the same set appeared consecutively. The three sets of items assigned to each test-phase task were randomly intermixed with the same restrictions.

Procedure. Participants were tested using the same apparatus and same general procedure as in Experiments 2 and 3, except that the sessions were conducted only in English. The encoding phase and test phase each had a block of picture-naming trials and a block of classification trials, with task order counterbalanced across participants. Encoding-phase blocks had 4 filler trials and 96 experimental trials; test-phase blocks each had 144 experimental trials.

Results

We processed RT data in the same way as in Experiment 2. Out of a total of 288 test-phase trials, 4.4% were removed because of response errors, 0.7% were removed because of machine errors, 4.3% were removed as spoiled trials, and 4.6% were removed as outliers. Thus, 86% of the trials were both correct and valid for the final analysis, about 41 items per condition per participant.

Encoding-phase RTs and error rates are given in Table 2. Test-phase RTs and error rates are given in Table 5. RTs for new items were longer for picture naming than for picture classification, t(47) = 11.66, p < .001. New item error rates were also higher for picture naming than for classification, t(47) = 6.25, p < .001. Repetition priming effects, shown in Figure 6, were reliable in all four repeated-picture conditions (ps < .05).
We submitted priming scores to a 2 (task match) × 2 (test task) repeated measures ANOVA. Overall, priming was stronger when the test task was naming than when it was classification, $F(1, 47) = 14.57, \text{MSE} = 6.594, p < .001$. Priming was greater when encoding and test tasks matched, $F(1, 47) = 78.59, \text{MSE} = 2.786, p < .001$. This was true for both picture naming, $t(47) = 8.56, p < .001$, and classification, $t(47) = 3.37, p = .002$. There was a significant interaction of test task and task match, $F(1, 47) = 39.10, \text{MSE} = 2.450, p < .001$. Within-task priming was greater for picture naming (141 ms) than for picture classification (52 ms), $t(47) = 7.16, p < .001$. However, between-task priming was symmetric across test tasks (29 ms for each), $t(47) = .005, p = .996$. That is, the magnitude of the between-task priming effect did not depend on which of the two tasks was the encoding task and which was the test task.

**Discussion**

Picture naming took longer than semantic classification of pictures and exhibited more facilitation than picture classification in the within-task repetition conditions as in previous research. Between-task priming was also reliable, and consistent with the principle of transfer-appropriate processing, repetition priming was stronger when the task matched from encoding to test than when it changed. The critical comparison of between-task repetition priming effects showed that facilitation from classification to naming and facilitation from naming to classification were equivalent, indicating that covert naming did not occur and that the processes facilitated in the between-task priming conditions are restricted to those of object identification.

Although the between-task priming effects were statistically reliable, they were smaller than the priming effects observed in the different-language naming conditions of Experiments 1 and 2. This discrepancy suggests that not all of the object identification processes required for picture naming are completed during semantic classification of pictures. The incomplete overlap in object identification processes could be because classification does not require the precise basic-level conceptual access required for picture naming. Consistent with this idea, neuroimaging research has shown that identifying and naming objects at a general level (manmade or living) did not recruit ventral stream visual cortex as far forward as naming objects at the basic level (Tyler et al., 2004). Another possibility is that classification and naming require access to different domains of semantic or conceptual information. Either way, a divergence in processing is indicated, and the smaller facilitation effect appears to be based on a set of processes that does not include the highest level components of object identification. On the basis of the symmetric between-task repetition priming effects observed, we incorporated semantic classification of pictures in Experiment 5 as an encoding task meant to facilitate object identification.

**Experiment 5**

The purpose of Experiment 5 was to provide a fourth test of the cognitive independence of object identification and word production processes in picture naming, using manipulations that could be implemented within a single language. Object identification was primed using semantic classification of pictures as in Experiment 4. As explained before, picture classification does not require the same degree of specificity in conceptual access as in picture naming; therefore, we did not expect it to facilitate some of the higher level picture identification processes necessary for picture naming.

In Experiment 5, word production was facilitated using a different-exemplar naming task. As explained in the introduction to Experiment 3, different exemplars of the same object concept require common word production processes for naming. Because

![Figure 6](image-url)
of their common structural properties, they also likely share high-
level object identification processes. These are the same common 
processes not eliminated when the exemplar and language changed 
from encoding to test in Experiment 3. Therefore, we expected that 
prior naming of a different exemplar would facilitate not only the 
word production processes of picture naming, but also some high-
level object identification processes.

Experiment 5 tested the independence of two sets of processes: 
(a) the set of lower level object identification processes shared by 
picture classification and naming and (b) the set of higher level 
object identification and word production processes shared when 
pictures of different exemplars are named. Thus, Experiment 5 
provides a somewhat different decomposition than the object 
identification–word production split that was addressed in Exper-
iments 1 and 2. The critical condition of Experiments 5A and 5B 
was one in which the same-exemplar classification and different-
exemplar naming tasks were completed on separate trials in the 
encoding phase.

Experiment 5 also provided two additional tests of whether 
semantic classification of pictures elicits covert naming. First, if 
semantic classification includes covert naming, and therefore both 
high-level identification and word production processes (except 
for articulation), then its processes overlap with those of naming a 
different exemplar, so the priming effects would exhibit a subad-
ditive interaction. To provide a stronger test, we included a con-
dition in which different exemplars were presented at encoding 
and test, with the task changing from classification to naming. 
Covert naming would lead to substantial facilitation in this con-
dition because semantic classification of a different exemplar 
would share the same processes with picture naming as naming a 
different exemplar (except for articulation).

We constructed parallel English and Spanish versions of the 
experiment for both scientific and practical reasons. This procedure 
was intended to make Experiment 5 more comparable to 
Experiments 1, 2, and 3, in that half of the combined data set 
would be based on English and half on Spanish picture-naming 
trials. Collection of data in both languages also allowed an assess-
ment of whether the patterns of priming are consistent across 
languages or specific to English or Spanish. This procedure was 
also based on participant availability, in that it was easier to recruit 
48 English speakers and 48 Spanish speakers than to recruit 96 
English speakers. Experiment 5A was conducted entirely in En-
GLISH with English speakers, and Experiment 5B was conducted 
e entirely in Spanish with Spanish speakers. The results are reported 
in a combined analysis with the experiment, and therefore the 
language, as a between-subjects factor.

Method

Participants—English speakers. Participants were 48 under-
graduate students (18 men and 30 women) at the University of 
Texas at El Paso who reported that English was their most fluent 
or only language. All were native English speakers or had begun 
learning English in early childhood. They ranged in age from 18 to 
29 (Mdn = 18). Of the 47 who reported ethnicity, 29 were 
Hispanic; 11, White non-Hispanic; 2, African American; and 5, 
Asian American. Two other students completed the procedure but 
were excluded and replaced because of low accuracy.

Participants—Spanish speakers. Participants were 48 stu-
dents (20 men and 28 women) at the University of Texas at El 
Paso ranging in age from 17 to 44 (Mdn = 20). All participants 
were native Spanish speakers; 44 reported that Spanish was 
their dominant language, and 3 reported similar fluency in 
Spanish and English (information was not available for 1 par-
ticipant). Most were recruited from a section of introductory 
psychology taught in Spanish. Of the 45 who answered the 
ethnicity question, all indicated Hispanic ethnicity. Two addi-
tional students completed the protocol but were excluded and 
replaced because of poor performance or prior exposure to the 
experimental pictures.

Design. The English and Spanish versions of the experiment 
each had a one-way design, with six encoding conditions manip-
ulated within subjects. Picture naming was the test task, and 
encoding conditions were defined by the relationship between the 
encoding task and the test task. The four encoding conditions 
critical to the hypotheses of independence included items not 
presented at encoding, items for which a picture of the same 
exemplar was classified, items for which a picture of a different 
exemplar was named, and items for which both of these tasks were 
performed on the same concept on separate trials. These conditions 
formed a 2 (same exemplar classified or not) × 2 (different 
exemplar named or not) factorial structure. We included an iden-
tical repetition condition in which the same exemplar was named 
in the same language at encoding and test to determine whether the 
combined effects would account for all processes involved in 
picture naming. We used the sixth encoding condition, in which 
the encoding task was to classify a picture of a different exemplar, 
to determine whether changing both the exemplar and the task 
from study to test would eliminate priming.

Materials. We selected picture stimuli from the same pool as 
for Experiments 2, 3, and 4. Three inclusion criteria were used: (a) 
availability of at least two different pictures, (b) unambiguous 
classification as natural or manufactured, and (c) names that were 
distinct from each other and unambiguous. This procedure resulted 
in the selection of 288 picture pairs for the English experiment 
(Experiment 5A) and 270 pairs for the Spanish experiment (Ex-
periment 5B). The median frequency of the English names was 15 
per million (Kuczer & Franc, 1967).

The two exemplars for each item were assigned to two sets, and 
the target set for final naming was counterbalanced across partic-
ants to control for any picture set or typicality effects. The 
pictures were randomly assigned to six sets of items (48 per set in 
English, and 45 per set in Spanish), and these sets were rotated 
through conditions across participants using a Latin square to 
control for specific item effects.

Procedure. Participants were tested using the same apparatus 
and general procedure as in Experiments 2, 3, and 4. The exper-
imental session was conducted entirely in English for Experiment 
5A and entirely in Spanish for Experiment 5B. The encoding phase 
had a block of picture-naming trials and a block of picture-
classification trials (natural or manufactured), with the order of 
tasks counterbalanced across participants. Each block had four 
filler items at the beginning and a rest halfway through. In the test 
phase, all experimental pictures were named in a block-
randomized sequence.
Results

We processed data in the same manner as in Experiment 2. Averaging across Experiments 5A and 5B, 0.6% of test-phase trials (three items from Spanish experiment) were excluded as stimulus list errors, 8.9% as response errors, 0.7% as machine errors, 9.1% as spoiled trials, and 4.3% as outliers. On average, 76.4% of test phase trials were included, or about 35 items per condition.

Encoding-phase RTs and error rates are given in Table 2. Test-phase picture-naming RTs and error rates are shown in Table 6 as a function of encoding condition and language of experiment. Repetition priming effects are shown in Figure 6. For the aggregate data, repetition priming was statistically reliable in all encoding conditions (p < .01) except for the condition in which the encoding task was classifying a different exemplar (p = .289).

We submitted the data from Experiments 5A and 5B to a combined analysis, with experiment, or language group, as a between-subjects factor. Test-phase RTs for the four critical encoding conditions were submitted to a 2 (same or different exemplar) × 2 (naming or classification at encoding) × 2 (language group) mixed ANOVA. Prior classification of the same exemplar facilitated naming, F(1, 94) = 14.09, MSE = 4,294, p < .001, as did prior naming of a different exemplar, F(1, 94) = 207.02, MSE = 4,201, p < .001. However, these two sources of facilitation did not interact (F < 1). None of the effects interacted significantly with language (all ps > .10), although responses were faster overall in the English experiment than in the Spanish experiment, F(1, 94) = 12.29, MSE = 67,999, p = .001. An examination of the priming scores clarifies that the magnitude of facilitation in the combined condition (120 ms) was indistinguishable from the sum of the facilitation effects for items in the same-exemplar classification and different-exemplar naming conditions (27 ms + 97 ms = 124 ms). These levels of facilitation are comparable to that observed for identical repetition (135 ms). When both the exemplar and the task changed from encoding to test, priming was essentially eliminated (11 ms).

Discussion

Picture naming was facilitated by prior semantic classification of the same exemplar to a similar degree as in Experiment 4. Prior naming of a different exemplar also elicited facilitation as in Experiment 3. The sum of these priming effects was equivalent to the priming obtained after both tasks were performed on separate trials in the encoding phase, indicating an additive pattern. The combined effect was also close to that of the identical repetition condition.

As in Experiment 3, relative to an identical repetition, changing the exemplar or task also reduced priming. When both the exemplar and the task were changed from encoding to test, priming was eliminated. This result indicates that covert naming did not occur during semantic classification because intentional covert naming would have resulted in substantial priming. Converging evidence that covert naming did not occur is that the effects of prior classification of the same exemplar and naming a different exemplar did not interact; therefore, they did not have overlapping processes (as they would have if covert naming had occurred).

There was no basis a priori to make predictions about systematic differences in priming patterns between the English and Spanish experiments. Although the Spanish-language experiment had longer RTs overall, language group did not interact with the effects of exemplar change, task change, or their interaction, and priming effects for identical repetitions were remarkably similar in English (134 ms) and Spanish (136 ms).

A Simple Quantitative Model of Bilingual Repetition Priming Effects

We derived a simple quantitative model as a way to formalize the critical hypotheses and test them across all experiments simultaneously. This procedure combines data across all experiments to assess deviations from additivity. Also, the model forces the quantitative assumptions to be consistent across experiments; for example, the object identification contributions are forced to be equivalent regardless of language proficiency or response language, something that is not done at the level of each experiment considered in isolation. It also forces monolingual word production to be the same across groups and languages in Experiments 4, 5A, and 5B. Thus, it tests whether conclusions about word production and independence hold up when contributions of component processes are quantified consistently across experiments.

Each experiment consisted of a set of repetition conditions meant to facilitate (or reduce facilitation in) object identification processes, word production processes, or both (as summarized in Table 1). As explained in the introduction, we made predictions based on a simple conceptualization of transfer-appropriate processing in which shared processes are the causal basis of priming. We wanted to test whether a simple linear instantiation of this

<table>
<thead>
<tr>
<th>Encoding condition</th>
<th>RT (ms)</th>
<th>Error rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>English Expt. 5A</td>
<td>Spanish Expt. 5B</td>
</tr>
<tr>
<td>Not presented</td>
<td>901</td>
<td>987</td>
</tr>
<tr>
<td>PN different exemplar</td>
<td>807</td>
<td>886</td>
</tr>
<tr>
<td>PC same exemplar</td>
<td>857</td>
<td>976</td>
</tr>
<tr>
<td>PN different exemplar &amp; PC same exemplar</td>
<td>778</td>
<td>869</td>
</tr>
<tr>
<td>PN same exemplar</td>
<td>767</td>
<td>851</td>
</tr>
<tr>
<td>PC different exemplar</td>
<td>876</td>
<td>991</td>
</tr>
</tbody>
</table>

Note. PN = picture naming; PC = picture classification.
logic could adequately account for the pattern of priming effects across the six experiments collectively, without introducing additional mechanisms. We also wanted to find out whether the collective set of effects can be explained by a linear model that treats object identification and word production as independent, sequential processes.

We assigned each component process of picture naming examined in this study a parameter to represent its contribution to repetition priming. Object identification was divided into two parameters, one representing lower level components and one representing higher level components, but values of these parameters were not allowed to vary across experiments. Object identification was assumed not to vary as a function of response language or participant proficiency (and therefore restricted to be equivalent across experiments). Word production processes were expected to vary systematically as a function of language proficiency, and the relative language proficiency of participants clearly differed across Experiments 1, 2, and 3 (with highly dominant, very balanced, and moderately dominant bilingual proficiency, respectively). For this reason, we allowed word production parameters to vary across the dominant and nondominant language and across the three bilingual experiments. We expected monolingual participants to exhibit smaller repetition effects than bilingual participants, and the dominant-language word production parameter for monolingual participants was not allowed to vary across the three single-language experiments (Experiments 4, 5A, and 5B). Finally, Experiment 4 had two conditions with picture classification as the test task, so we added a parameter to account for the processes in picture classification not shared with picture naming. This parameter was only needed for the identical picture classification repetition condition and was not critical to testing any of the central hypotheses.

To summarize, the preceding logic required the inclusion of three types of process parameters: object identification (with two components), word production (with four proficiency levels for the dominant language and three proficiency levels for the nondominant language), and classification response. This comes to a total of 10 process parameters. For any individual condition, the maximum number of process parameters involved was three (two object identification component parameters and either a word production parameter or a classification parameter).

Fitting the Independence Model

Table 1 lists the 38 experimental conditions, 38 corresponding linear expressions (combinations) of process parameters that indicate the sets of processes shared by the encoding and test tasks in each condition, and the 38 observed priming scores. Each linear expression was set equal to its observed priming score, thus forming a system of 38 linear equations. Fitting the model involved finding the best solution to this set of equations, using a least-squares fitting procedure (i.e., choosing the set of parameter values that minimizes the sum of the squared discrepancies between the model and the observed priming scores). The model estimates of priming (based on the best simultaneous solution) are given in the final column of Table 1 for each condition. With 38 free data points and the 10 process parameters described above, the model had 28 degrees of freedom. The model explained 98.6% of the variance in the observed mean priming scores, and the root-mean-square error was 10.58 ms.

The parameter estimates of priming contributions derived from this procedure were reasonable. The lower level and higher level object identification estimates were 33 ms and 42 ms, respectively; thus, the total object identification estimate was 75 ms. Estimates of the word production parameters varied systematically across languages and proficiency levels. Word production in the dominant language had the smallest priming contribution with the monolingual and highly dominant speakers in the single-language experiments (56 ms). The greater contributions of dominant-language word production in Experiments 1, 2, and 3 (94 ms, 181 ms, and 107 ms, respectively) were positively related to proficiency in the nondominant language. Contributions of word production in the nondominant language (249 ms, 194 ms, and 186 ms for Experiments 1, 2, and 3, respectively) were inversely related to proficiency in the nondominant language. The contribution of the classification response parameter was small (19 ms).

Comparisons of Alternative Models

Although the additive independence model was a good fit to the pattern of observed repetition priming, we also considered whether a model that allowed for process overlap or nonindependence would fit even better. A parameter for an additional shared process was added to the linear expression for every condition. An additional parameter was added to the combined-manipulation conditions to allow and measure any additional benefit of a second practice of that process; this parameter was constrained to values from a minimum of 0 to a maximum of the value of the shared process parameter. (Built into this model is the constraint that priming in the combined condition is greater than or equal to that of the identical repetition condition, as illustrated in Figure 2C.) With these two parameters added to the 10 original process parameters, there were 12 parameters. A fit of this model estimated the additional benefit parameter at 0, so it was removed and an 11-parameter model (process parameters + shared process parameter) was used (root-mean-square error = 10.33). The priming contribution of the shared process was estimated to be only 6.1 ms. The difference in fit associated with the additivity restriction was not significant, $F(1, 27) = 1.326, MSE = 150, p = .260$, and the difference in root-mean-square error was only 0.25 ms. Therefore, the additive model with fewer parameters was preferred.

General Discussion

In the following sections, we review the results and their implications with respect to several themes. The first two sections detail the component processes of object identification and word production that were facilitated and the evidence for their independence. The independence finding along with other aspects of the data have implications for several issues in memory, including implications for categories of implicit memory, the mechanisms underlying repetition priming, interpretations of transfer-appropriate processing, and the effects of process difficulty. Implications for picture–word processing include how language proficiency affects learning, whether nontarget language representations are accessed and covertly named, and whether amodal concepts are accessed.
Repetition Priming in Object Identification and Word Production

Object identification processes were facilitated when participants named the picture in another language (Experiments 1 and 2) or semantically classified the picture at encoding (Experiments 4 and 5). Changing the pictured exemplar of a concept from encoding to test reduced facilitation of identification processes relative to an identical repetition (Experiments 3 and 5). Considering these findings in conjunction with past research, we can narrow down the processes of object identification that were facilitated and what processes correspond to those components labeled as lower level and higher level identification processes.

It is unlikely that processes that correspond to what perception researchers term low-level vision (e.g., edge detection, orientation and spatial frequency filtering, and segmentation) contribute substantially to the observed priming effects. As explained in the introduction, previous research has suggested that such processes do not exhibit item-specific repetition effects, specifically that simple low-level transformations of a pictured object do not reduce repetition priming relative to an identical repetition, and neuroimaging studies have likewise shown no neural priming in early visual cortex. Processes at this level appear to be overlearned.

The lower level processes facilitated in the present study are at a level that is specific to a particular instance (exemplar) of an object category and common to semantic classification and naming tasks, perhaps the processes of completing a structural description and matching it to a visual object category in long-term memory. A contribution of exemplar-specific object identification processes to priming is indicated by a reduction in RT priming when the exemplar changed from encoding to test (Experiments 3 and 5), as seen in previous research. This exemplar-specific object identification priming likely corresponds to parts of the reduction of neural priming in extrastriate and fusiform cortex observed when an exemplar was changed from study to test (Koutstaal et al., 2001). The finding that changing viewpoints reduced priming but not as much as changing the exemplar (Bartram, 1974) additionally indicates that exemplar-specific priming has both viewpoint-specific and viewpoint-general components.

We speculate that the viewpoint-specific processes facilitated are those of using output from low-level processes of early visual areas to form a structural description and that this corresponds to the neural priming observed in extrastriate cortex (V4; Sayres & Grill-Spector, 2006; Wagner et al., 1997). Because different views of the same object have the same structural description, the viewpoint-general processes may be those of matching that structural description to an appropriate basic-level visual object category. This component of RT priming may correspond to the neural priming observed in the fusiform cortex (posterior inferotemporal), which has areas tuned to different object categories (e.g., Martin et al., 1996).

The high-level processes are at a level that generalizes across exemplars of an object category but is not accessed in semantic classification of pictures. The use of bilingual materials made it possible to demonstrate the existence of exemplar-general object identification priming, with the critical finding being that changing both the exemplar and the response language from study to test did not eliminate priming (Experiment 3). We speculate that this exemplar-general priming corresponds to matching a visual object category to an amodal conceptual representation. These processes would likely correspond to neural priming in left anterior inferotemporal cortex and/or left inferior frontal cortex, areas for which priming was not diminished when an exemplar was changed from study to test (Koutstaal et al., 2001).

Word production processes of picture naming were facilitated when participants translated words to the target picture-naming language (Experiments 1 and 2) or named a different exemplar picture (Experiment 5). Changing the response language from encoding to test reduced facilitation of word production relative to an identical repetition (Experiments 1, 2, and 3). Although we did not attempt to separate processes within word production, previous research helps to specify further what processes were facilitated.

It is unlikely that articulation processes contributed substantially to the word production priming effects observed in this study or in previous research. On the basis of studies including conditions to measure priming from picture naming to word naming (Durso & Johnson, 1979; Durso & O’Sullivan, 1983) and priming of picture naming on the basis of prior generation of a homophone in response to a definition (Wheeldon & Monsell, 1992), the average estimate of item-specific priming due to repeated articulation was only 10 ms, which was not reliable in any case. Also, when naming was covert at encoding, therefore not requiring articulation, priming was not reduced relative to identical repetition (Brown et al., 1991). Similarly, repetition of word production tasks like word naming, verb generation, and picture naming did not reduce activation in cortical areas thought to be involved in planning and executing articulation (Kerr, Gusnard, Snyder, & Raichle, 2004; Raiche et al., 1994; van Turrenout et al., 2003). Thus, articulation appears to be overlearned, at least in monolingual speakers. However, it is possible that bilingual individuals would exhibit some priming for articulation in the less practiced nondominant language. Nevertheless, the observed priming effects are more likely due to faster retrieval of the lemma and phonological word form. A different set of manipulations could perhaps separate the contributions of lemma and phonological word form retrieval.

Independence of Identification and Production Processes in Picture Naming

We combined the selective influences on object identification and word production using additive-factors methodology in Experiments 1, 2, 3, and 5. Experiments 1, 2, and 3 were bilingual, therefore providing separate tests or replications in each language, and Experiment 5 had separate tests in English and Spanish instantiations, so in essence there were eight tests of additivity. For these eight tests, there was no case in which the manipulations meant to facilitate or reduce facilitation in object identification and word production processes elicited a significant interaction or deviated substantially from linear additivity.

A central finding in this study was that the main effects of object identification priming and word production priming were essentially additive; their interaction was negligible. To substantiate this finding, it was important to go beyond merely showing that the relevant interaction effects were statistically nonsignificant. The findings are more strongly established through replication, use of large data sets, estimating effect sizes for interactions and main effects, and using a mathematical model that incorporates data from all of the experiments.
The first strategy was replication. Across experiments, we varied the specific manipulations used to influence object identification and word production processes, language proficiency of participants, and the difficulty of vocabulary. Within each bilingual experiment, manipulations were replicated in their two languages, and the single-language experiment was replicated in two languages. Across experiments and languages, there were eight tests of independence, each yielding a pattern suggesting independence of the two influences.

The second strategy was to use larger data sets than those typically used in either repetition priming research or bilingual research and to keep all manipulations within subjects to increase power and stabilize estimates. The data sets were large both in terms of the number of participants and in terms of the number of trials that participants completed in each experimental condition. Experiment 1 was the smallest, with 48 participants and nine trials per cell, yielding 432 data points per cell (Encoding Condition × Language), which is closer to the typical experiment size in research on repetition priming or bilingual language processing, but after that we collected larger data sets. The numbers of data points collected per cell were 2,560 in Experiment 2, 2,000 in Experiment 3, 2,304 in Experiment 4, 2,304 in Experiment 5A, and 2,160 in Experiment 5B.

The third strategy was to show that the interaction effects were small in both an absolute sense and relative to the main effects. Estimates of effect size (partial $\omega^2$) were calculated for the interaction of the selective influence manipulations on priming in each experiment and converted to Cohen’s $d$. For Experiments 1, 2, and 5, the $F$ value was less than 1, so the estimated effect size was 0. For Experiment 3, the estimate was 0.05, a very small effect. In contrast, the effect sizes of the individual process manipulations were larger. For manipulations meant to affect object identification, effect sizes ranged from 0.30 to 0.53; for manipulations meant to affect word production, effect sizes ranged from 1.18 to 1.93. Thus, the deviations from linear additivity were small relative to the effects of the individual process manipulations.

Finally, we derived a mathematical model as a way to formalize the critical hypotheses and test them across all experiments simultaneously. As explained in the section on the quantitative model, the pattern of priming effects was explained well by a model in which priming contributions of object identification and word production processes were treated as independent and sequential. Fit of the model was not substantially or reliably improved when a parameter to allow process overlap or subadditivity was included.

The assumption that overlapping processes would have led to subadditive priming effects was not tested here, but previous research has shown that multiple picture-naming trials at encoding were subadditive with both identical repetition (Gollan et al., 2005; Wiggs et al., 2006) and partial repetition (Bartram, 1974). That is, the effect of having two presentations was less than twice the effect of a single presentation, reflecting the diminishing benefit of successive practice trials. We did not assume that a second practice of an overlapping process would increase facilitation, but in the studies of multiple picture-naming repetitions, additional practice was beneficial.

Because proving a null hypothesis of no interaction is not possible, neither is it possible to prove that the processes are independent, sequential, or nonoverlapping. However, we have shown that the overlap or dependence is so small relative to the other effects of interest so as to render it inconsequential, and we do not lose substantial explanatory power by ignoring any overlap or dependence that might exist.

Types of Implicit Memory and Repetition Priming

These dissociations of object identification and word production support a distinction between identification and production forms of repetition priming. Gabrieli et al. (1999) have 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 attention manipulations. However, the present study differs from Gabrieli et al.’s research in that picture naming was not considered an identification task, but rather a complex task with its own dissociable identification and production components. Operationally, this means that the distinction was made within rather than across repetition priming paradigms. As can be seen from the model estimates, the relative contribution of production processes to repetition priming in picture naming varied as a function of language proficiency. For monolingual participants, the proportion of the identical repetition effect attributable to word production was 43%; for bilingual participants in the dominant language, it was 63%; and for bilingual participants in the nondominant language, it was 74%. Thus, although both identification and production priming are evident across levels of proficiency, the proportion based on production decreases with proficiency in the response language.

Basis of Repetition Priming in Picture Naming

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 that can be observed in both RT and neural activity. The priming observed following partial repetitions (when stimulus or response differs) in previous studies also rules out the possibility that repetition priming is the learning of a simple stimulus–response pairing. However, these studies did not rule out the possibility that repetition leads to a cognitive “shortcut,” using a more direct processing route from the stimulus to the response, cutting out some of the processes that intervene on the first experimental exposure. In fact, such a change in processing route based on a learning-related change in neural circuitry has been one of the major explanations offered for neural repetition priming effects, primarily on the basis of the finding that repeated word production leads to increased activation of the left insular cortex (Raichle et al., 1994; van Turrenout et al., 2003). However, this finding does not necessarily imply a route change because there is no compelling evidence that this region is part of the “critical path” for word production, so it could correspond to a change in processing incidental to the task.

Several aspects of the present data and previous research would be difficult to explain under a shortcutting mechanism. First, the fact that the partial repetitions were both linearly independent and also accounted for the full identical repetition effect shows that there are no macro-level cognitive shortcuts even in the case of identical repetition. Furthermore, in previous research, picture-
naming performance continued to improve beyond the first repetition, following a smooth learning curve in both RT (Bartram, 1974; Gollan et al., 2005) and neural response (van Turrenout et al., 2003).

A sounder explanation is that each nonoverlearned cognitive process is speeded with repetition according to its own learning function; both object identification and word production are executed more quickly when repeated. Besides the learning curve exhibited for picture naming in RT and neural response, both object identification tasks like semantic classification (Sayres & Grill-Spector, 2006) and word production tasks like verb generation (e.g., Kerr et al., 2004; Raichle et al., 1994) show typical learning functions in RT. Additional evidence for speeded processing is the repetition-related activation reductions in several of the regions implicated in picture naming itself. Two neural mechanisms consistent with the speeded processing approach include neural tuning and long-term potentiation (Grill-Spector et al., 2006; van Turrenout et al., 2003). Tuning is a process by which a set of neurons becomes more selective, or narrows the range of stimuli or inputs to which it reacts; therefore, the number of neurons that respond to a given input decreases with repetition. Long-term potentiation is a process by which an increase in synaptic efficacy leads to specific neurons or sets of neurons becoming more efficiently activated. This neural explanation is analogous to the speeded process explanation for the cognitive-level effect.

**Conceptualizations of Transfer-Appropriate Processing**

Separate from the question of what actually happens to processing with repetition is the question of what conditions cause priming to occur and how these conditions determine priming magnitude. Nearly all explanations of repetition priming on this level involve commonalities between encoding and test, but the commonalities between encoding and test tasks deemed critical to or predictive of facilitation have been operationally defined in several ways, as explained in the introduction. The two major classes of transfer-appropriate processing interpretations are those that define similarity in terms of representations or nodes and those that define similarity in terms of processes or links.

An explanation based on activation of common representations at encoding and test could account for the substantial effects with partial repetition and their attenuation relative to identical repetition. However, it cannot accommodate the additivity of the effects that we claim to be based on shared object identification and shared word production processes or the equivalence of priming in the combined and identical repetition conditions. The reason is that picture naming in a different language from the target and translation to the same language as the target would both involve activation of a common amodal concept, and the combination of these effects would be subadditive because the second activation of the amodal concept in the combined condition would not increment priming as much as the first activation. The model analysis also shows that allowing for an extra repeated process in the combined conditions does not improve model fit, and the estimate of the contribution of that second repetition is only 6 ms. A representation-based account also cannot handle the previous finding that generating a word in response to a definition in one language does not facilitate generating the translation equivalent as a picture-naming response (Monsell et al., 1992). To begin to accommodate such findings in a representation-based model, one would have to assume that translation equivalents do not have a shared level of representation, which is contradicted by the literature (see Francis, 1999).

The data of the present study are better accommodated under a conceptualization of transfer-appropriate processing based on processes completed rather than representations activated. Although the results of many previous studies can be accommodated under either type of model, some can be explained only under the process approach. An important example is the finding that priming of picture naming based on prior production of a word in response to a definition did not transfer across languages, even though presumably a common concept was accessed (Monsell et al., 1992). These conclusions apply to repetition priming as measured by decreases in RT, but it is certainly possible that other types of priming (e.g., those measured by changes in accuracy or bias to generate previously presented items) have distinct bases.

Schacter, Dobbins, and Schnyer’s (2004) recent stimulus specificity, associativity specificity, and response specificity conceptualization can explain some aspects of our data, including priming in the conditions in which either the stimulus or the response was repeated, and more priming when both were repeated. In fact, no aspect of the present data directly contradicts it. However, that approach does not make clear how to determine the point at which stimulus processing ends and associative processing begins, or when associative processing ends and the response begins. Furthermore, the separate labels for types of specificity can be more parsimoniously accommodated under a single repeated process mechanism. For example, in our approach, when the stimulus or response matches from encoding to test, corresponding processes also match; therefore, any finding that can be explained by the three-specificities approach can also be explained by our approach.

**Transfer-Appropriate Processing and Process Difficulty**

One implication of the transfer-appropriate processing logic used in this study is that more difficult processes will exhibit stronger priming. This assertion is not the same as to say that tasks with longer mean RTs will exhibit larger difference scores. Tasks with longer RTs usually do exhibit larger priming effects under conditions of identical repetition, but we argue that it is because tasks with longer RTs have a profile of component processes that are slower or less well learned. (Technically, difficulty is not the time taken by the process but the difference between the time taken and the asymptotic time that would be obtained with infinite practice.)

The magnitude of repetition priming effects is not simply a monotonic function of the baseline RT of the test task. Counterexamples can be seen by comparing conditions meant to facilitate object identification across tasks in Experiment 4 and across languages in Experiments 1, 2, and 3. Priming between picture naming and picture classification was symmetric across the two tasks, even though picture-naming RTs were much longer than picture-classification RTs (Experiment 4). For bilingual participants, even though RTs were longer in the nondominant language, facilitation based on prior naming in the opposite language was similar to that for final picture naming in the dominant and nondominant languages (Experiments 1 and 2; Francis et al.,
Similarly, a manipulation meant to reduce facilitation in object identification, changing the exemplar, had comparable effects in the dominant and nondominant languages (Experiment 3).

In word production, the magnitudes of the facilitation effects were positively associated with process difficulty. For bilingual participants, manipulations meant to affect word production in the nondominant language had stronger effects than those meant to affect word production in the dominant language (Experiments 1 and 3). Word production priming varied systematically with bilingual proficiency across experiments, with nondominant-language word production manipulations having their greatest effect and the dominant language having its weakest effect in Experiment 1. The estimated contribution of word production priming (based on the model) was even weaker in the monolingual Experiments 4 and 5, consistent with a previous finding that monolingual participants exhibited less priming than bilingual participants when naming pictures in their dominant language (Gollan et al., 2005).

Overall, the language-specific processes of word production were primed more in the nondominant language, where there was more room for improvement, parallelizing effects of word frequency (Wheeldon & Monsell, 1992) and age of word acquisition (Barry, Hirsh, Johnston, & Williams, 2001) on word production priming in picture naming. In contrast, the encoding conditions meant to selectively influence the language-general process of object identification did not exhibit this pattern; the influences were similar regardless of response language. Thus, the present results show that difficulty effects can operate on one component process without operating on another independent component process in the same task. Therefore, difficulty and the effects of difficulty on performance are best defined at the process level.

Conceptual Access in Bilingual and Monolingual Picture Naming

The pattern of RTs and priming effects is consistent with concept mediation in bilingual picture naming and translation and inconsistent with word mediation. One indicator of concept mediation is priming between translation and picture-naming tasks (Sholl et al., 1995). This effect was substantial in both languages in Experiments 1 and 2. In monolingual and bilingual participants, the priming from different exemplars supports the conclusion that picture naming is concept mediated (Experiments 3 and 5). The longer RTs for picture naming than for classification (Experiments 4 and 5) replicate results of previous research taken to indicate that picture naming in monolingual participants is concept mediated (e.g., Potter & Faulconer, 1975).

Given that the hypotheses and interpretations in the present study were based on a model of picture naming in which an amodal concept is accessed, it is of interest to consider whether the data patterns could be accommodated within a model that does not include amodal concepts, such as Paivio’s (1991) dual-coding theory, and whether the interpretation of the data would be different. In dual-coding theory, there are no amodal concepts, but semantic information is represented in modality-specific representations within verbal systems for each language and an image system. Correspondences between the three systems can be made through a translation process. Within this model, processes shared by picture naming in different languages are those leading up to access to semantics of the image. Processes shared by translation and picture naming with a common response language are those leading from semantics of the response language to the overt response itself. Neither of these encoding tasks covers the translation process from the image to the target language. Therefore, the combined priming effects would be expected to fall short of the identical case in Experiments 1 and 2, but this is not what happened.

Effects of Bilingual Proficiency and Consequences of Practice

Priming effects with identical repetition were stronger in the bilingual experiments than in the single-language experiments (as in Gollan et al., 2005), stronger in the nondominant language than in the dominant language (Experiments 1 and 3), and stronger for bilingual participants who were less fluent in their nondominant language (comparing across Experiments 1, 2, and 3). As can be seen most clearly in the model estimates of word production priming, these effects reflect differences in word retrieval difficulty. Monolingual individuals have produced words in their vocabulary many more times than bilingual individuals, and bilingual individuals have produced words many more times in their dominant language than in their nondominant language. These differences in exposure lead to different levels of strength in the concept–word association, with bilingual individuals having “weaker links,” especially in the nondominant language (Gollan, Montoya, Cera, & Sandoval, 2008). Therefore, the pattern is consistent with the idea that these items are at different points on the learning curve.

An interesting consequence of the encoding-phase practice trials was that because priming was stronger for the nondominant language than for the dominant language in bilingual participants, and stronger for the dominant language in bilingual participants than in monolingual participants, the effect of proficiency on RT was smaller for repeated items than for new items. Bilingual and monolingual participants also differed less after several repetitions than on the first picture-naming trial (Gollan et al., 2005). Analogous effects arose in single-language studies in which repetition decreased the discrepancy between easier and more difficult items because difficult items benefited more from repetition. In picture naming, repeated items showed reduced effects of name agreement (Park & Gabrieli, 1995), word frequency (Bartram, 1974; Wheeldon & Monsell, 1992), and age of acquisition (Barry et al., 2001). Long-term extraexperimental consequences of multiple repetitions can be seen in the effects of frequency of word use over time. In comparing monolingual, bilingual dominant-language, and bilingual nondominant-language picture-naming RTs, low-frequency words show large differences, but high-frequency words show much smaller differences (Gollan et al., 2008). Thus, with more exposures over time, individual words benefit less and less from the greater number of repetitions experienced by monolingual or bilingual participants in the dominant language.

If the encoding-phase picture-naming trial is considered as an episodic learning trial in a negatively accelerated learning function, then words in a bilingual individual’s dominant language are further along on the learning curve, presumably because they have had more previous exposures. Encoding-phase practice presumably strengthens the processing paths used to complete the task. In previous research, a single encoding-phase picture-naming trial produced long-term learning lasting for weeks in monolingual
participants (e.g., Cave, 1997; Mitchell & Brown, 1988) and for at least a week in bilingual participants (Francis & Sa´enz, 2007). In bilingual participants, the object identification component showed no evidence of decay, whereas the word production component was reduced by 39% across a 1-week interval but still remained strong. Also, neural priming for covert naming did not decrease substantially across 3 days (van Turrenout et al., 2003). Therefore, a large portion of the priming effect observed after several minutes does reflect long-term learning.

Related to this phenomenon, many studies of bilingual language production have given participants training on the experimental items, practicing them several times before performing the critical experimental trials or using the same items for several conditions for the same participant (e.g., Abunuwar, 1992; Costa et al., 2000). Presumably, this procedure was incorporated because of the high error rates and variability in RTs in unpracticed production. The purpose has been to get the RTs to a stable level before measuring the effects of the independent variables, and having them practiced to asymptote also allowed for using them in multiple conditions without having a confound from practice or priming effects. However, this approach ignores the episodic consequences of the training exposures. The present results, along with the other studies cited above, suggest that not only extensive training but even a single training trial for each item can have the unintended consequence of reducing the effects of language proficiency or item characteristics, perhaps underestimated their influences.

Access to Nontarget Lexical Representations

As explained in the introduction, several recent results have suggested that name access in bilingual picture naming is nonselective with respect to language and that there are consequences of that access for immediate processing (e.g., Costa et al., 1999). In the present study, we addressed the issue of whether words in the nontarget language are activated during picture naming and have a long-term influence with the additive factors model. The approach was based on the idea that if picture naming in one language elicited covert naming in the other language, then it would facilitate later word production in that other language, just as intentional covert picture naming has been shown to facilitate later overt naming in monolingual individuals (Brown et al., 1991). If participants had covertly named pictures in the nontarget language on every trial, then priming between languages would not have been substantially lower than priming within languages (Experiments 1, 2, and 3) because only the negligible articulation component of priming would be eliminated. If covert naming had occurred either on a smaller proportion of trials or in an incomplete manner, then the contributions of different-language naming and same-language translation to repetition priming would have been subadditive; however, they were additive in both languages, showing that different components of picture naming were facilitated (Experiments 1 and 2). It remains possible that activation spread to representations of the corresponding word in the nontarget language without actual covert naming, but because the facilitation effects were not subadditive, we can conclude either that the nontarget language was not activated or that the effects dissipated across the retention interval.

An analogous issue is whether semantic classification of pictures elicits covert naming. Although semantic classification of pictures does not require access to the name (e.g., Potter & Faulconer, 1975), some memory results in the literature suggest spontaneous covert naming of pictures when no encoding instruction was given (Brown et al., 1991; Paivio & Csapo, 1969). Whether it would occur when a specific alternative task was assigned was unknown. This issue was addressed in Experiments 4 and 5, and three aspects of the data support the conclusion that covert naming did not occur. First, priming between picture classification and picture naming did not depend on which was the encoding task and which was the test task (Experiment 4); had covert naming occurred, priming would have been greater when classification was the encoding task. Second, priming in picture naming was eliminated when the encoding task was semantic classification of a different exemplar (Experiment 5). Third, same-exemplar classification and different-exemplar naming at encoding produced additive effects on later picture naming (Experiment 5). It remains possible that representations of the word corresponding to the picture were activated without covert naming, but with effects that dissipated over the retention interval.

Previous memory studies in which covert naming was indicated had no specific encoding-task instruction. Paivio (1991) has suggested that under such conditions, spontaneous covert naming occurs only when sufficient time is given to process each picture at encoding, based on changes in the picture superiority effect in recall found with different encoding-phase stimulus presentation rates (Paivio & Csapo, 1969). The fast-paced nature of the semantic classification task in Experiments 4 and 5 along with the instruction to perform classification may have prevented this type of processing, and a similar logic can be applied to covert naming in the nontarget language in picture naming in Experiments 1, 2, and 3.

Research on dual-task performance suggests that it is not possible to select or prepare two different responses simultaneously, including when one of the tasks is picture naming. In word production, a processing bottleneck occurs during retrieval of the lemma and phonological word form, which are response selection processes, but not in articulation, which is execution of the response (Ferreira & Pashler, 2002). The pace of the encoding-phase picture naming in Experiments 1, 2, and 3 may have been too fast for participants to also select the translation equivalent. Similarly, the encoding-phase semantic classification in Experiments 4 and 5 may have gone too fast for participants to also covertly select the picture name. It is possible that activation spreads to the nontarget language but selection does not occur, consistent with Costa et al.’s (1999) model of bilingual picture naming and lexical access in which activation and selection have different processing consequences. Intentional selection of a verbal response may be necessary for long-term word production priming to occur.

Conclusions

The patterns of priming effects observed conformed to a straightforward discrete sequential model with negligible interaction, which implies that object identification and word production are independent and sequential processes. Picture naming and word translation tasks both involved access to amodal concepts. However, bilingual participants did not covertly name pictures in
the nontarget language and monolingual participants did not covertly name pictures that they semantically classified; if incidental activation of such verbal representations occurred, it had no lasting effect.

The priming results indicate that transfer-appropriate processing predictions are better made in terms of processes than in terms of representations and that encoding exposures result in the speeding of component processes rather than changes in processing routes. The speeding of word retrieval processes depended on language proficiency, with the greatest benefit observed in bilingual participants’ nondominant language, a smaller effect in bilingual participants’ dominant language, and still smaller effects in monolingual participants, consistent with a typical learning curve. In contrast, object identification priming did not depend on language proficiency. The patterns of repetition priming observed were therefore entirely consistent with a transfer-appropriate processing model of repetition priming, in which shared processes are the causal basis of priming effects and the magnitude of priming effects is determined by the difficulty of the shared processes.

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Received January 3, 2007
Revision received January 3, 2008
Accepted January 4, 2008

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