Analogical Transfer of Problem Solutions within and between Languages in Spanish–English Bilinguals

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Previous cognitive research on transfer of learning in bilingual participants has used simple tasks such as word learning. In the present study, an analogical transfer paradigm was used to examine transfer of high-level conceptual information between languages. Experiment 1 examined analogical transfer from a single source story to a target problem in the same or in a different language with Spanish–English bilinguals. Experiment 2 exploited the competitive nature of retrieval in analogical transfer using a more sensitive design in which the target problem was preceded by two source analogs suggesting different solutions. Even with a total of 207 participants across the two experiments, transfer was not significantly or substantially affected by the match or mismatch between the languages of the source and target problems. However, in Experiment 2, the competition between alternative source analogs was greater when the languages of the two analogs matched than when they mismatched. These experiments show that the aspects of memory representations important for higher-order processes such as analogical transfer are primarily language-general and that language-specific features play only a minor role when retrieving and applying information relevant to problem-solving.

Key Words: bilingualism; problem solving; memory; similarity; cognition.

Inputs to human memory come in many forms. Because much of the information we learn comes through the medium of language, it is important to understand the status of input language in the resultant memory representation. Some record of the specific linguistic units used to convey a message must be encoded at least temporarily in order for a person to comprehend the input. It is not clear, however, whether these linguistic units remain as a fundamental part of the long-term memory representation for that information or whether later access to the memory representation depends on the particular language route through which the information was encoded.

The nature of the relationship between language and thought has puzzled philosophers, linguists, and psychologists for many decades. Conclusions have ranged from the view that language is the primary organizer of thought (Watson, 1930; Whorf, 1956) to the view that all language input is recoded into a nonlinguistic form, or conceptual code (Chomsky, 1957). These two views underlie two models of the organization of bilingual memory, one in which items learned in different languages are stored in two separate conceptual systems and one in which they are integrated in one common conceptual memory system.

The focus of this article is the question of whether information encoded by means of one language is more accessible later in that same language than in another language. In other words, in the context of a new situation in English, will information learned in English be more accessible than information learned in Spanish? More generally, this article explores the extent to which surface characteristics of...
input, such as language, during the learning of new information, restrict later access to that information. For the present investigation, the question will be limited to high-level processes generally referred to as “analogical transfer.”

COGNITIVE STUDIES OF LANGUAGE INTEGRATION IN BILINGUAL MEMORY

The vast majority of the cognitive studies of language integration in bilingual memory have been conducted using series of words, each word presented in isolation as a stimulus. The experimental studies most relevant to the current problem were early studies that specifically addressed the question (posed by Kolvers, 1963) of whether episodic memory stores for information learned in each language are shared or separate. Two such lines of experimentation have shown that “episodic” systems in bilingual memory must be at least partly shared by the two languages at the word level. One set of experimental studies has shown that having to remember the language of an input in addition to its meaning impairs performance and thus requires additional memory resources (Lambert, Ignatow, & Krauthamer, 1968; Nott & Lambert, 1968; Tulving & Colotla, 1970). A second set has shown that output during recall of bilingual word lists is clustered more by semantic category than by language, indicating that language is not as strong an organizer of episodic memory as is semantic category (Dalrymple-Alford & Aamiry, 1969; Lambert et al., 1968; Nott & Lambert, 1968).

The conclusions drawn from these word-list studies do not necessarily generalize to memory for information learned by means of natural language. Complex conceptual information, such as causal relationships, cannot be conveyed by single words; more complex linguistic structures are required. A second advantage to using natural language rather than word lists is that the goal in processing natural language is more likely to be comprehension of the message. There is experimental evidence that sentences are automatically processed conceptually even if the externally imposed goal is not comprehension (MacKay & Bowman, 1969; Murphy & Shapiro, 1994; Sachs, 1967, 1974), but isolated words are not necessarily processed at a conceptual level (see, e.g., Srinivas & Roediger, 1990). In fact, memory for the content, or meaning, of a sentence or text passage outlasts memory for the exact wording of the same sentence or text passage (Sachs, 1967; 1974). Finally, natural language materials also allow for more justifiable generalization to everyday language processing. To date, there have been relatively few cognitive bilingual studies that incorporate natural language materials.

The nature and degree of language integration in bilingual memory has been a widely debated issue and has motivated a large number of experiments (Francis, 1996, in press; Keatley, 1992). Interestingly, the organization of bilingual memory systems has not received much attention in the cognitive bilingual literature during the past 20 years. Recent efforts have focused more on language representations or memory representations of translation equivalents than on memory for information learned through the medium of language.

ANALOGICAL TRANSFER

If conceptual information conveyed by means of natural language is learned in a manner that gives privileged access to the language used for encoding, then units of conceptual information encoded in the same language should be more easily compared or integrated than units encoded in different languages. If conceptual information is learned in a way that gives equal access to both language systems, the language match between units should not matter. The present study investigated whether information encoded by means of two different languages can be integrated as well as information encoded in the same language by using a series of analogical transfer experiments.

Two situations are considered to be analogous if they contain parallel sets of causal relationships. Analogical transfer occurs when a person draws upon knowledge about one situation in order to make inferences about the other situation. The analogical transfer paradigm is ideally suited to studying memory for high-level conceptual information in bilinguals for four reasons. First, an important measure of
learning is not simply recalling information when asked to do so, but spontaneously recognizing situations where the information is relevant and applying it. That is, analogical transfer is an important indicator of learning, from a practical point of view. Second, analogical transfer involves primarily high-level conceptual processing. Past research on memory for word series consistently showed transfer between languages for tasks that were based primarily on conceptual processing, although sometimes these effects were attenuated relative to within-language transfer effects (see Francis, 1996, in press). Third, both automatic and controlled processes can be examined. Automatic processes are best tapped in memory protocols that incorporate incidental encoding and an indirect retrieval task. Indirect retrieval is also a way to avoid a strategic use of covert translation. The analogical transfer procedure involves incidental learning of a problem solution within a particular story context. The initial test of transfer is indirect, in that when the target problem is presented, no reference is made to the previously presented source analog. As an additional bonus, a subsequent direction to apply the source analog to the target problem can be used to measure controlled transfer processes. Fourth, analogical transfer can be (and usually is) assessed using natural-language materials. Natural language allows for the study of processing of high-level conceptual information such as the causal relationships involved in problem solutions.

Analogical transfer is particularly useful in problem solving. A number of single-language studies have examined the degree of transfer between analogous problem solutions (i.e., problems with identical causal structure) under a variety of conditions or relationships between the analogous problems. Participants read either a text passage in which a problem analogous to the target problem, a source analog, is described and its solution is given or a passage in which a problem not analogous to the target problem is described and solved. Subsequently, participants are asked to solve the target problem. The transfer effect is that participants are more likely to give the target (i.e., analogous) solution to the problem if they have read the analogous problem and its solution than if they have not read the analogous problem.

Three steps necessary to enable successful analogical transfer from one problem-solving situation to another are (1) encoding, or forming a mental representation of the source and target situations, (2) retrieving the source analog (the previously presented analogous problem), or noticing that it is relevant, and (3) mapping the features of the source analog to the current situation (Gentner, 1989; Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987). The importance of the retrieval process is indicated in several studies in which a specific instruction to give the solution suggested by the source analog resulted in higher solution rates than when participants were not directed back to the source analog (e.g., Catrambone & Holyoak, 1989; Gick, 1985; Gick & Holyoak, 1980, 1983; Spencer & Weisberg, 1986). These studies show that spontaneous transfer (i.e., without a hint) depends on both retrieval and mapping, but directed transfer (i.e., with a hint) removes the necessity of the retrieval (reminding) process and thus depends primarily on mapping.

THE ROLE OF SIMILARITY IN ANALOGICAL TRANSFER

Before proceeding, it is important to point out that the terms used to describe similarity are not universal. In the analogical transfer literature, surface similarity typically refers to a common semantic domain or to common objects or concepts, but this term is also used to refer to surface modality. However, in bilingual research, researchers typically work at the level of the single word, so these sorts of conceptual or object similarity are considered deep (at least at the level of a single word), and shallow refers more to orthography, phonology, or surface modality. At the sentence level, the more complex relational structure is considered deep, and the individual components may be considered surface features.

In the four major models of analogical transfer (Reeves & Weisberg, 1994), similarity is a crucial determinant of transfer (Gentner, 1983; Hintzman, 1986; Holyoak, 1985; Ross, 1984).
In cognitive theories of similarity, Gentner (1989) has made an important distinction between object similarity and relational similarity. Object-attribute similarity is similarity of properties of individual objects; relational similarity is similarity of the relationships within different pairs or groups of objects or among properties of a single object. Support for this distinction has come from studies showing that relational similarity comparisons are generally more difficult than object similarity comparisons and appear to require language or symbolic processing. For example, children are able to choose a target based on object similarity before they are able to choose a target based on relational similarity (Gentner & Ratterman, 1991). Also, similarity judgments are affected differently by variations of object similarity and variations of relational similarity (Goldstone, Medin, & Gentner, 1991).

In analogical transfer research, Holyoak and Koh (1987) have made a similar distinction, using the terms surface similarity to denote similarity in features that are not causally relevant, such as objects mentioned in or the context of a story and structural similarity to denote similarity in causal structure. These types of similarity had different effects on analogical transfer; both surface and structural differences reduced transfer before a hint to use the source analog, but after this hint, only structural differences reduced total transfer. Surface differences affected only before-hint transfer. In particular, several manipulations of surface similarity have shown retrieval-specific effects on transfer, including other small changes in central objects, characters, or elements of a source analogy (Daehler & Chen, 1993; Keane, 1987), changes in substantive context or semantic domain (Bas Sok & Holyoak, 1989; Keane, 1987), and changes in the presentation context, such as experimental setting, description of task, and time delay (Catrambone & Holyoak, 1989; Spencer & Weisberg, 1986). Thus, in analog retrieval, both surface and structural features serve as cues, but in analogical mapping structural similarity is very important and surface similarity is not. Patterns of results supporting this same conclusion have been shown in studies of transfer from picture analogies to verbal problems (Chen, 1995) and between mathematical word problems (Ross, 1987). Gentner (1989) likewise emphasized the importance of surface features in retrieval and structural similarity in mapping.

Somewhat confusing this issue is the fact that not all surface similarity manipulations have the retrieval-specific effect seen in the preceding examples. Some types of surface similarity manipulations do not appear to affect transfer at all. These types include changes in the perceptual form of the source analog and changes in words, objects, or diagrams not central to the analogy (Gick, 1985; Gick & McGarry, 1992). There are other surface similarity manipulations that affect the mapping process, for example switching the roles of central objects or entities from the source to target problem (Ross, 1989). Because of this variety in transfer patterns seen for surface similarity manipulations in single-language experiments, even if we consider input-language consistency to be a surface similarity, it is not clear what effects it will have on analogical transfer.

BILINGUAL ANALOGICAL TRANSFER

Now consider what might happen in an analogical transfer experiment in which the languages of the source analog and target problem are varied. The two primary processes in analogical transfer, retrieval and mapping, access different aspects of the encoded representations of the source and target analogies. Retrieval depends highly on surface features of the analogies, whereas mapping depends primarily on the structural features of the analogies. A set of surface and structural features must be encoded both for the source analog and for the target problem. If the source and target problem are learned in different languages, then the features corresponding to each are learned in different languages. Related features learned in different languages may be stored in a common system or in separate systems, yielding language-general or language-specific access to these representations, respectively. Research on bilingual memory shows both patterns, typically more language-general results for conceptual aspects of
memory and more language-specific results for nonconceptual aspects. This characteristic of bilingual memory suggests that different aspects of analogous stories learned in different languages may have different types of representations. Further, and because the processes of retrieval and mapping access different aspects of the representations, these two components of transfer may differ in their degrees of language generality/specificity. On the one hand, the primary information retained after reading a text passage is the gist, or meaning structure of the passage (Sachs, 1967, 1974). On the other hand, memory research has shown numerous times the importance of transfer-appropriate processing, a match between processes used in encoding and retrieval of memories (Morris, Bransford, & Franks, 1977).

Thus, there are two processes under examination, retrieval and mapping, and each process may be either language-specific or language-general. Under language-general processing, matched-language and mismatched-language performance are equivalent. Under language-specific processing, mismatched-language performance is impaired relative to matched-language performance. Thus, there are four possible combinations, each yielding a distinct set of predictions. Recall that, as shown in previous studies, mapping is important to the solution rates both before and after a hint, whereas retrieval is important only to “before-hint” processes.

The first possibility is that neither retrieval nor mapping depends on whether the languages of the source analog and target problem were the same or different. Transfer rates between and within languages would be equivalent both before the hint and overall. As explained in the previous section, several manipulations of surface similarity yield this pattern. Obtaining this pattern with an input-language manipulation would indicate strong language generality—that related concepts learned by means of different languages are interconnected in a common conceptual system and that only language-general information is important for analogical transfer.

The second possibility is that a language mismatch between the source analog and target results in impaired retrieval but intact mapping relative to matched-language performance. Because retrieval affects transfer only before the hint, this combination would result in lower transfer rates between than within languages before the hint, but equivalent total transfer rates. This pattern is the most common for similarity manipulations that are not causally relevant.

The third possibility is that language affects the mapping process but not the retrieval process. This combination would result in lower transfer rates both before the hint and overall, because mapping affects both of these rates. (Note that this pattern has been observed for role-reversal manipulations (Ross, 1989).) Such a result might indicate that language is a structurally relevant feature of input, in that input language may affect the causal structure of the resultant mental representation. Although the structural features of a text description should be the same in any language version of the same problem (provided that the translation used to produce them is adequate), the reader’s mental representations of the causal structures may not be identical.

The final possibility is that both retrieval and mapping are impaired when the languages of the source analog and target problem differ, resulting in lower transfer rates between languages than within languages both before the hint and overall. Structural similarity manipulations typically produce this pattern. In the case of bilingual analogical transfer, such a result would suggest that sets of related concepts learned in different languages are stored in separate conceptual systems or that analogical transfer depends to some extent on some lower-level features that are language specific. Although an extreme language-specific model is ruled out by the cognitive bilingual studies described earlier, a more reasonable version, one in which concepts learned in different languages have weaker connections between them than concepts learned in the same language, is possible.

A dimension orthogonal to language consistency is a bilingual’s proficiency in each of his or her languages, which may also affect transfer. When bilinguals process information in their nondominant language, they may comprehend less or process the information more slowly, thereby forming a less complete mental
representation of the information than if it were learned in their dominant language. Additionally, output of information, or language production, in one’s nondominant language makes a greater demand on cognitive resources than output in the dominant language. These difficulties in processing the nondominant language may impair encoding, retrieval, or mapping when the source story or target problem is in the nondominant language.

EXPERIMENT 1

The first bilingual analogical transfer experiment used the simplest design in which within-language and between-language analogical transfer could be compared. Spanish–English bilinguals attempted to solve a problem after having read either an analogous problem and its solution or a neutral (unrelated) problem and its solution, either in the same language or in different languages. On their first attempt to solve the problem, no reference was made to the preceding source story. In order to compare this measure of spontaneous transfer to a measure of directed transfer, those given the analogous story were subsequently instructed to give the solution to the new problem that was suggested by the source analog.

The particular source analog and target problem pairing was selected to have a maximal transfer rate within languages. That is, with this set of materials, the base rate of target solutions is very low (about 10%) without exposure to an analogous source story, and the solution rate is very high (about 70%) with exposure to the particular source analog used (Gick & Holyoak, 1980, 1983; Holyoak & Koh, 1987). Thus, a wide discrepancy was expected between solution rates in control conditions and in analogous, matched-language conditions. The mismatched language performance could reasonably fall anywhere along the range from control to matched-language levels. This procedure maximized the power to detect differences between mismatched-language performance and either matched-language or control performance. For example, if we were to obtain a between-language transfer rate around half the magnitude of the within-language transfer rate, we should have enough statistical power to say that it was reliably greater than control but reliably smaller than the within-language effect. If the within-language effect were small, the sample size required would be prohibitive.

Method

Participants. The participants were drawn mainly from introductory psychology classes at the University of California, Los Angeles. A total of 152 students who met the eligibility requirements participated, of whom 137 were included in the final analysis. Participants were self-identified Spanish–English bilinguals, who indicated that they spoke both languages “fluently” and that either English or Spanish was their first language. Ten participants who indicated that they had prior experience with the experimental problem were excluded, and two participants were excluded for failure to follow instructions. Finally, the 3 participants who indicated that they spoke Spanish much better than English were excluded, because they had trouble with the experimental materials.

The final set of 137 participants included 89 females and 40 males (8 participants did not indicate their gender on the experiment form). The mean age was 19.7 years old. Thirteen of the participants had started learning English before they started learning Spanish; 104 had started learning Spanish first and then English; and 19 had started learning both languages at the same time (1 participant did not indicate which language was learned first).

Participants were divided into groups based on their self-rated relative proficiency in spoken Spanish and English. The groups were defined by ratings on a 9-point relative proficiency scale.1 Forty participants who agreed with the

1 The self-report language proficiency scale had nine points: (a) I do not speak Spanish; (b) I speak Spanish, but I do not speak it fluently; (c) I speak Spanish fluently, but not nearly as well as I speak English; (d) I speak Spanish almost as fluently as I speak English; (e) I speak Spanish and English with equal fluency; (f) I speak English almost as fluently as I speak Spanish; (g) I speak English fluently, but not nearly as well as I speak Spanish; (h) I speak English, but I do not speak it fluently; (i) I do not speak English. Participants were instructed to rate their level of fluency (proficiency) in spoken Spanish by circling the appropriate statement.
statement “I speak Spanish fluently, but not nearly as well as I speak English,” formed the highly English-dominant group. Fifty participants who agreed with the statement “I speak Spanish almost as well as I speak English” formed the slightly English-dominant group. Forty participants who agreed with the statement “I speak Spanish and English equally well,” and seven who agreed with the statement “I speak English almost as well as I speak Spanish” were combined to form the equivalent-and-Spanish-dominant group.

All participants in this study were highly proficient (fluent) speakers of Spanish and English, who used both languages in their daily lives. The categorization into proficiency/dominance levels was within this already restricted group. Other volunteers who did not speak both languages adequately were not eligible for or were excluded from the study. The reason for attempting to divide the participants into levels at all was to find out whether these differences would covary with performance or with language effects in analogical transfer. A range was used because (1) as a rule, bilinguals do not have equal proficiency in their two languages (i.e., equal proficiency is simply a cognitive theoretical ideal (Hakuta, Ferdman, & Diaz, 1987)), and (2) this variability allows generalization of the results to bilinguals outside the ideal of equally balanced proficiency. No appropriate Spanish-dominant population was available. Finding such a population would have altered other controls, such as the source and educational background. To recruit the sample from which our data were collected, the UCLA Psychology Department subject pool was carefully screened over a period of 2 years to obtain enough participants with high enough proficiency in both languages.

Materials. The target problem that participants were asked to solve was Duncker’s (1945) radiation problem. The passage used as the source analog was the Holyoak and Koh (1987) Lightbulb story. The passage read by participants in the unrelated story condition was a story entitled the Wine Merchants (Gick & Holyoak, 1980). The particular version of the Lightbulb story used in the present experiment (i.e., the laser/fragile glass version) was the one used by Holyoak and Koh as the high surface/high structural similarity source analog to the radiation problem. Spanish versions of these three passages were created by translating the original English versions. Minor wording deletions, substitutions, or rearrangements were made to make the translations as similar as possible in meaning. Some assurance of translation quality was obtained by consultation with native speakers of Spanish who had university-level education in Spanish. The text of the source stories and target problem are given in Appendix A.

Procedure. Participants were tested individually or in small groups. When they came to the experimental session, they were told (in English) that they would be doing a variety of reading and writing tasks in English or Spanish and answering questions about their language background. Before the experiment began, students were asked to rate their relative proficiency in English and Spanish on the 9-point labeled scale. Instructions for page turning (each task was to be completed on a separate page) were given in English by the experimenter. Written instructions for individual experimental tasks were given in either English or Spanish, consistent with the languages of the tasks.

The first experimental phase was exposure to either the source analog or the nonanalogous story. Participants were given 3 min to read the source analog or the nonanalogous story and rate how difficult it was to understand that story on a 10-point scale (ranging from 1, very easy to understand, to 10, very difficult to understand). They were then given 5 min to write a summary of the story. The instructions were given and the summary was to be written in the same language as the presented source story. During this time, participants were allowed to refer back to the story.

Between the first and second experimental phases, there was an intervening task, a three-page language background questionnaire that took between 8 and 15 min to complete. (The timing for this questionnaire was not strictly controlled). The second experimental phase was
target problem solution. Participants were given 5 min to read the Ray Problem and attempt to solve it. The response was to be written in the same language as the presented problem. No reference was made to the source analog. At the end of the 5 minutes, they were asked to rate how difficult it was to understand the problem on a 10-point scale. Participants in the analogous story conditions were given 3 more minutes to write the solution suggested by the earlier story (whether they had already given that solution or not). This hint was given in the language of the target problem. Participants in the nonanalogous conditions had no comparable phase. Upon completion of the experiment, all participants were asked whether they had seen either of the stories before this experiment, and then they were debriefed. Each experimental session lasted approximately 40 min.

**Design.** Three experimental between-subjects factors, Type of Story (Analogous or Nonanalogous), Language of Story (English or Spanish), and Language of Problem (English or Spanish), were crossed. One three-level subject characteristic variable, Relative Language Proficiency (equivalent proficiency or Spanish dominant, slightly English dominant, and highly English dominant) was also crossed with the three manipulated factors. The 113 participants in the analogous conditions were randomly assigned to the four language combinations, distributing participants from the three proficiency groups as evenly as possible among conditions. Because there was no theoretical basis for expecting nonanalogous solution rates to differ among conditions or language proficiency groups, a smaller number of participants (24) was divided among the four nonanalogous control conditions. The main dependent variable was whether the analogical solution was given before the hint, only after the hint, or not at all.

The assignment of the Lightbulb story as the source analogy and the Ray Problem as the target was kept constant for three reasons. First, because this is the order most commonly used in prior studies, using this order allows more justifiable comparisons of the present results to the results of those studies. Second, the transfer between any pair of problems is asymmetric, so including both assignments adds an extra source of error variability. To examine the assignment of problem to source or target as a factor was not a central issue for the present study.

**Results**

Participants responded appropriately across all conditions, in that 96% of the answers took the form of problem solutions (i.e., suggested a specific course of action to take). Answers also generally conformed to the instruction to use the rays to solve the problem, with 96% of before-hint solutions including use of the rays, though 14% of participants also gave at least one solution suggestion that did not include use of the rays.

**Language proficiency.** As indicated earlier, three measures of relative language proficiency in the two languages were originally considered: a self-report rating of relative proficiency, a measure of balance in years of exposure, and a measure of balance in age of acquisition. The self-report rating was moderately correlated with the two alternative measures ($r = .42$). The latter two measures were indistinguishable ($r = 1.00$) because of the restricted age range of introductory psychology students. A series of logistic regression models showed that the self-report measure was more helpful than the other measures in predicting analogical transfer performance patterns, whether considered alone or with its interaction terms. Inclusion of the exposure balance measure or age of acquisition measure (with or without interaction terms) added little if anything to the predictive power of the design variables and added nothing beyond what was predicted by the proficiency rating.

Group differences in relative English and Spanish proficiency were also reflected in their comprehension difficulty ratings. Mean English and Spanish comprehension difficulty ratings for the source analog were compared across the three groups using a two-way unweighted-means between-subjects analysis of variance. Stories presented in Spanish were rated signif-

Further details of this analysis are available from the author.
significantly more difficult ($M = 3.6$) than stories presented in English ($M = 1.8$), $F(1,106) = 25.84$, $p < .001$. The interaction between language proficiency group and language of story was significant, $F(2,106) = 3.18$, $p < .05$, such that the difference in mean difficulty ratings of English and Spanish stories was greatest for the highly English-dominant group (1.6 vs 4.8 for English and Spanish stories, respectively), smaller for the slightly English-dominant group (1.6 vs 3.5), and smaller still for the equivalent- and Spanish-dominant group (2.3 vs 3.0).

**Analogous solutions.** The main analyses were of convergence solutions, solutions analogous to the solution described in the Lightbulb story. The defining feature of this solution type is that the rays are directed at the tumor from different directions. Responses were coded in their original languages by bilingual coders. Two responses were coded for each participant: the before-hint response (i.e., the response given before the instruction to use the source story) and the total solution, the pair of before-hint and after-hint solutions taken together. The reason for coding total responses rather than after-hint responses is that participants often only gave a rough summary of their answer if they had already given the convergence solution before the hint. Coding of before-hint solutions was blind to whether the prior story was analogous or nonanalogous to the language of the source story. Coding of total solutions was blind to the language of the source story. Reliability of the coding was checked by having two independent raters code each response. First-pass agreement was 95% (Cohen’s $\kappa = .90$), and consensus was reached on all discrepancies.

Before-hint and total solution rates for the four language conditions are shown in Table 1 and were analyzed separately (as in most other analogical transfer studies). None of the 24 participants in the nonanalogous conditions generated the target (convergence) solution. When the three language proficiency groups were combined, transfer relative to control (nonanalogous condition) performance was evident both before and after the hint in all language conditions (all $G^2(1) > 9$, $p < .01$).

Comparisons among the language conditions and language proficiency groups were made in a

### Table 1

<table>
<thead>
<tr>
<th>Solution stage</th>
<th>Language conditions (Source–Target)</th>
<th>Highly English dominant ($N = 33$)</th>
<th>Slightly English dominant ($N = 41$)</th>
<th>Equivalent and Spanish dominant ($N = 39$)</th>
<th>All groups combined ($N = 113$)</th>
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</thead>
<tbody>
<tr>
<td>Before-hint solutions</td>
<td>English–English</td>
<td>.78</td>
<td>.50</td>
<td>.71</td>
<td>.67</td>
</tr>
<tr>
<td></td>
<td>English–Spanish</td>
<td>.20</td>
<td>.42</td>
<td>.67</td>
<td>.42</td>
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<tr>
<td></td>
<td>Spanish–English</td>
<td>.57</td>
<td>.60</td>
<td>.54</td>
<td>.57</td>
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<tr>
<td></td>
<td>Spanish–Spanish</td>
<td>.14</td>
<td>.18</td>
<td>.90</td>
<td>.43</td>
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<tr>
<td>Total solutions</td>
<td>English–English</td>
<td>.89</td>
<td>.75</td>
<td>1.00</td>
<td>.88</td>
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<td></td>
<td>English–Spanish</td>
<td>.40</td>
<td>.75</td>
<td>.78</td>
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<tr>
<td></td>
<td>Spanish–English</td>
<td>.71</td>
<td>.80</td>
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<tr>
<td></td>
<td>Spanish–Spanish</td>
<td>.29</td>
<td>.82</td>
<td>.90</td>
<td>.71</td>
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<tr>
<td>Retrieval parameter</td>
<td>English–English</td>
<td>.88</td>
<td>.67</td>
<td>.71</td>
<td>.76</td>
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<td></td>
<td>English–Spanish</td>
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<td>.22</td>
<td>1.00</td>
<td>.60</td>
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</table>
four-way contingency table, treating these three predictors as fixed factors and the solution type as the outcome variable. Hierarchical tests of linear log-frequency models were made to test the effects of interest while taking the full design structure into account (following Wickens, 1989). Likelihood ratio statistics ($G^2$) were calculated for each restriction of the model. Simple effects and interactions within each proficiency group were tested in three-way contingency tables.

The language of the target problem was an important determinant of transfer. Overall, before-hint solution rates were higher when the target problem was in English than when the target problem was in Spanish ($G^2(1) = 3.99, p < .05$). The advantage for English target over Spanish increased with decreased proficiency in Spanish ($G^2(2) = 9.83, p < .01$). The simple effect of language of target problem was significant for the highly English-dominant group ($G^2(1) = 9.27, p < .01$), but not for the other two groups ($p > .10$). This effect was driven by differences among the groups in Spanish target solution rates, which were low for highly English-dominant (18%) and slightly English-dominant (30%) groups and higher for the equivalent-and-Spanish-dominant group (79%). In contrast, the English target solution rates were comparable for the three proficiency groups at 69, 56, and 60%, respectively. This pattern also led to a main effect of proficiency group ($G^2(2) = 8.07, p < .05$), with the equivalent-and-Spanish-dominant group performing at a higher level overall.

After the hint, the pattern of solution rates was similar, except that the slightly English-dominant group performance shifted from the level of the highly English-dominant group to the level of the equivalent-and-Spanish-dominant group. The effect of language of target problem was still significant for the highly English-dominant group ($G^2(1) = 7.47, p < .01$), but solution rates for English and Spanish target problems were nearly identical for each of the other two proficiency groups ($G^2(1) < .01, p > .50$). This time, the interaction between target problem language and proficiency group was not statistically significant ($p > .10$). The main effect of language group was significant ($G^2(2) = 7.87, p < .05$), with the highly English-dominant group performing worst overall.

In contrast to the effect of target problem language, the language of the source analog did not significantly affect before-hint or total transfer for any of the language proficiency groups or for the three groups combined (all $ps > .25$). This effect cannot be explained by the relative difficulties of the source story and target problem texts; that is, the idea that the source story is simply easier to understand. In fact, the source story text was rated, if anything, somewhat more difficult to comprehend (1.8 in English and 3.6 in Spanish) than was the target problem text (1.4 in English and 2.8 in Spanish).

Consistent with language-general retrieval and mapping, the match or mismatch between source and target language did not significantly affect transfer before or after the hint for any of the proficiency groups or for all groups combined (all $ps > .10$) except that an advantage for matched language over mismatched language approached significance after the hint for participants in the equivalent-and-Spanish-dominant group ($G^2(1) = 3.21, p < .10$). However, there was no evidence of an interaction of language match with proficiency group ($p > .25$). Overall, in analogous conditions, there were 52 cases with consistent language stories and 61
with inconsistent language stories. When comparing the consistent and inconsistent language groups, 54 and 49%, respectively, gave the target solution before the hint. After the hint, the consistent and inconsistent solution rates were 79 and 70%, respectively. Therefore, the mismatched-language solution rates were 91 and 89%, respectively, of the before-hint and after-hint solution rates of the matched language condition.

Retrieval and mapping. Recall that the central cognitive question in this experiment is how the reminding and mapping processes of analogical transfer are affected by the language variables, in particular the consistency of language between the source and target. The solution rate analyses answer this question only indirectly, because the solution rates are not pure measures of these processes. The before-hint solution rates in particular are influenced by both retrieval and mapping. To estimate the success rates of the retrieval and mapping processes more directly, the analogical transfer task can be broken into steps that are accomplished probabilistically. First, a person might have an insight, with probability $I$, that allows them to solve the target problem without the help of the analogous source story. If they do not, they might spontaneously retrieve or notice the relevance of the source analogy, with probability $R$. After either noticing the relevance spontaneously or having the relevance pointed out, they may be able to map the source analogy (with probability $M$) and apply the solution to the new target problem.

The present analysis constitutes a formalization of this decomposition developed by Francis (1996; Francis & Wickens, submitted for publication), which involves translating this probabilistic structure into a multinomial processing tree (Batchelder & Riefer, 1990; Riefer & Batchelder, 1988). Most inferences about retrieval and mapping success rates based on standard solution rate comparisons require the same or similar assumptions; thus, this model is implicit in the logic of several other studies of analogical transfer.

The parameters corresponding to the success rates for insight ($I$), retrieval ($R$), and mapping ($M$) were estimated algebraically for each language condition using the following equations:

$I = \frac{\text{nonanalogous condition solution rate}}{\text{total solution rate}}$; $M = \frac{\text{nonanalogous condition solution rate}}{\text{total solution rate} - I} - (1 - I) \div \text{total solution rate} - I$; $R = \frac{\text{before-hint solution rate} - I}{\text{total solution rate} \div \text{total solution rate}}$.

No participant in the nonanalogous conditions gave a convergence solution; therefore, the direct estimate of $I$ from the data is zero. As can be seen from the equations, this is a special case, and the other equations simplify to the following: $M = \frac{\text{total solution rate} - I}{\text{before-hint solution rate} \div \text{total solution rate}}$. Estimates of the mapping parameter $M$ are displayed as the total solution rates in Table 1. Estimates of the retrieval parameter $R$ for each condition are displayed in the lower panel of Table 1.

$R$ and $M$, the parameters of interest, were compared across conditions and groups. The language of the source analog had little effect, if any, on either retrieval or mapping. The language in which the target problem was presented and solved, in contrast, had effects at both the retrieval and the mapping stages. Retrieval success was greater when the target problem was in English than when it was in Spanish for both of the English-dominant groups, but the effect was in the opposite direction for the equivalent-and-Spanish-dominant group. Particularly interesting was the pattern shown by the slightly English-dominant group; when the target problem was in Spanish, retrieval performance was no better than that of the highly English-dominant group, but mapping performance was at the level of the equival-

Because it is unlikely that the true (i.e., population) value of the insight parameter $I$ is zero, $R$ and $M$ parameters were derived across a range of reasonable Insight ($I$) rates to be sure that the original pattern was not specific to the choice of $I = 0$. The pattern of the parameter estimates was consistent across this range.

The effects of language proficiency and language consistency are more clearly understood by examining the pattern of retrieval and mapping parameter values across conditions than by examining goodness of fit in a hierarchy of multinomial models. The fits of these models can be evaluated using a program developed and described by Hu and Batchelder (1994) but cannot at present represent the full structure of the multiway factorial design used in the present experiment.
alent-and-Spanish-dominant group. This pattern was not clear from the before-hint solution-rate analysis, in which the slightly English-dominant group showed, if anything, better performance than the highly English-dominant group. As seen in the total solution rate analysis, the highly English-dominant group had greater mapping success when the target problem was in English than when it was in Spanish, but the language of the target problem did not affect mapping for the other two proficiency groups.

There was no indication of a positive language consistency effect on the retrieval process. (For the slightly English-dominant group, the effect is, if anything, in the wrong direction of better retrieval for mismatched languages.) As shown in the total solutions analysis, the equivalent-and-Spanish-dominant group showed a pattern weakly favoring matched languages for mapping. Combining the three proficiency groups (weighting cases equally), the overall retrieval rate for mismatched-language conditions (.70) was 103% of the rate for matched-language conditions (.68). The mapping rate for mismatched conditions (.70) was 89% of the rate for matched conditions (.79). Clearly, neither of these differences is statistically reliable.

Discussion

For bilingual participants with unequal proficiency in English and Spanish, analogous solution rates were lower when the target problem was in their weaker language (here, Spanish). The multinomial model analysis showed that the retrieval process was more prone to impairment than was the mapping process. It is not surprising that the language of the target problem affected transfer more than did the language of the source analog. To encode the source analog, it is necessary only to comprehend it, whereas in order to solve the target problem, one must both comprehend it and be able to express its solution in the target language. On the other hand, one must rely on memory to access a source analog, whereas the target problem can be consulted repeatedly if necessary. It is surprising, however, that there was no corresponding effect of language of the source analog on solution rates or on the retrieval and mapping success rates. Such an effect would certainly be expected with less proficient bilinguals.

Clearly, language consistency does not have the dramatic effect on transfer that is seen in other studies with manipulations of conceptual surface similarity and structural similarity. The match between the language of the source analog and the language of the target problem had no appreciable effect on analogous solution rates before or after the hint and was not in a consistent direction across proficiency groups. A power analysis showed power between .75 and .80 to detect a 25% difference between matched-language and mismatched-language solution rates in the four-way contingency table. The multinomial model analysis likewise showed no benefit from language consistency in the retrieval process. The only indication of an advantage for matched languages was a marginally significant effect for the equivalent-and-Spanish-dominant group in the mapping success rates (here, equivalent to the total solution rates). The most obvious explanation for the generally comparable performance in matched and mismatched language conditions is that both the retrieval and the mapping processes are language-general, and language consistency is not important for analogical transfer. In the next experiment, a more sensitive design is utilized, one that maximizes the expected effect size.

EXPERIMENT 2

Many problems can be solved in more than one way. Thus, when faced with a new problem, it is common to have several relevant events or knowledge structures to draw upon. The approach taken in solving a target problem depends on the particular analogous situation retrieved from memory and its solution method (Gick & Holyoak, 1980, 1983). A long history of memory research has shown that retrieval of items from memory is competitive (e.g., McGeech, 1932; Melton & Irwin, 1940). When two items in memory are associated with the same cue, they compete for retrieval when that cue is given. More recently, competition has been found in analogical reminding (Wharton, 1993;
Wharton, Holyoak, Downing, Lange, Wickens, & Melz, 1994). In the analogical reminding paradigm, after reading a series of stories, participants were presented with either related sentences or related new stories and asked to tell which of the original stories they were reminded of. While effects of structural consistency were minimal in noncompetitive reminding conditions (those in which only one related story had been presented), a marked advantage for consistent over inconsistent analogies was repeatedly observed when those two types of analogies were put in competition with each other.

In analogical transfer specifically, Francis and Wickens (1996, 1998) demonstrated that competitive processes affect retrieval of potential source analogies for transfer in problem solving. Competition changed the relative transfer rates of two analogous source stories that suggested different solution types, increasing the advantage for source analogs with higher surface similarity to the target problem. Their study also established that competition affected the process of spontaneously retrieving the source analog, not encoding, mapping, or application. The pairing of solution methods with each of the two analogous source stories was switched (i.e., counterbalanced) across the two experiments. This manipulation revealed that competition was based primarily on the similarity of source story contexts to problem solving context rather than the salience of a particular solution type.

Because competition was shown to magnify similarity effects in these previous studies, competition was exploited in Experiment 2 of the present study to create more sensitive tests of whether the language of source analog and the language match between source and target affect transfer. The radiation (tumor) problem has at least two reasonable solutions that do not violate the explicit constraints of the problem. One solution is the convergence solution, which was the target solution in Experiment 1. Another solution is the open-passage solution, which involves finding a route for high-intensity rays to attack the tumor in such a way that no rays come into contact with healthy tissue. Because the tumor is located in the stomach, one such solution is to access it through the esophagus. The convergence and open-passage solutions were used as target solutions in Experiment 2.

Bilingual participants read two source analogs, one with a convergence solution and one with an open-passage solution. For half of the participants, one source analog was in English, and the other was in Spanish. Putting the same-language and different-language analogs in competition with each other enabled a more direct comparison of transfer rates than was possible in Experiment 1. This competition paradigm also allowed for the use of materials nearly identical to those used by Francis and Wickens (1996, 1998). The particular set of materials chosen from that study was the set exhibiting the largest competition effect. These materials were adapted for translation into Spanish. The target problem was consistent with Experiment 1 of the present study, and one of the source analogies used the same Lightbulb story context, but with reduced surface similarity (i.e., the low surface similarity version from Holyoak & Koh (1987)).

**Method**

**Participants.** Ninety-four Spanish–English bilinguals were drawn from the same population as in Experiment 1. Eligibility requirements were the same as in Experiment 1, except that no one who had participated in Experiment 1 could participate in this experiment. Five other participants were excluded from analysis: two because they indicated that they were already familiar with the target problem and three because of failure to follow instructions.

The final set of 94 participants consisted of 63 females and 27 males (4 participants did not indicate their gender on the experiment form) with a mean age of 18.8 years. Thirteen of the participants had started learning English before Spanish, 69 had started learning Spanish before English, and 12 had started learning both languages simultaneously. According to the same 9-point rating scale used in Experiment 1, 26 participants rated themselves as highly English dominant, 35 rated themselves as slightly En-
English dominant, and 33 rated themselves as having equivalent proficiency or as slightly Spanish dominant.

Materials. The target problem was Duncker’s (1945) radiation problem. The passages used as source analogs were adaptations of the Lightbulb story (ultrasound version (Holyoak & Koh, 1987)) and the Fortress story (open supply route version (Gick & Holyoak, 1980)). Some rewriting was done to make the two source analogs more different from each other than in the original versions of these two stories (but nearly identical to the versions used by Francis & Wickens, (1996, 1998)). Spanish versions of these passages were created by translating the English versions. These materials are given in Appendix B.

There were two reasons to use only one pairing of solution principle with source story. First, because overall rates of the solution types, overall effectiveness of the two source stories, and the interactions between solution type and source story were not of particular interest, keeping this aspect of the materials consistent across conditions would minimize error variability. Second, Francis and Wickens (1996, 1998) have already crossed these solution principles and source story contexts with English language materials to better understand the basis of the competition effect. The combination of solution principle with source story context that resulted in the most marked competition effects was chosen for the present study.

Procedure. Participants were tested individually or in groups of up to eight students. At the beginning of the experimental session, they were asked to rate their relative proficiency in English and Spanish. As in Experiment 1, written instructions were always given in the language of the particular task to be completed.

In the first experimental phase, participants read and summarized the two source analogs. Participants were given 3 min to read the first source analog (the Fortress) and rate how difficult it was to understand on a 10-point scale. They were then given 5 min to write a summary of the story, looking back at the story if necessary. After summarizing the first source analog, participants were given 3 min to read and rate and 5 min to summarize the second source analog (the Lightbulb). Between the first and second experimental phases, participants were given 5 min to complete a questionnaire about their language background.

The second experimental phase was target problem solution. Participants were given four opportunities to solve the problem. First, participants were given 5 min to read and attempt to solve the target problem, with no instruction to refer back to either source analog. Participants were then asked to rate how difficult it was to understand the target problem. Next, participants were given a nonspecific hint, that others had found it useful to consider one of the stories read earlier, and they were given 4 more minutes. The nonspecific hint given was worded as follows: “When trying to solve the Ray Problem, some people have found it easier if they consider one of the stories that you read earlier. Now try to think of a solution to the Ray Problem that is suggested in one of the earlier stories.” The particular source analog that might be helpful was intentionally left ambiguous. In Spanish target problem conditions, this hint was given in Spanish. On the third and fourth opportunities, participants were asked whether they had tried to use each source analog to help them solve the target problem, and they were given 3 min to provide the solution suggested by each of the two source analogs. At the end of the experiment, participants were asked whether they had seen any of the materials before, and they were debriefed.

Design. Three experimental between-subjects factors were crossed in this design: Language of the Lightbulb story, Language of the Fortress story, and Language of the Ray Problem. Each factor had two levels, English and Spanish. The order of presentation of the two source analogs was kept constant, with the Fortress story always presented first and the Lightbulb story always presented second. The original 99 participants were distributed as evenly as possible among the eight experimental conditions. After the five necessary exclusions the numbers in each condition ranged from 11 to 13. Participants at the three levels of proficiency were distributed similarly across conditions.
Results

Coding. Responses were coded in their original languages by bilingual coders. Each response was coded as a convergence solution, an open-passage solution, or neither of the target solution types, using a lenient coding system. Any response that suggested shooting rays at the tumor from different directions was coded as a convergence solution. Any response that suggested finding or creating an open route through which to aim rays at the tumor without contacting the healthy tissue was coded as an open-passage solution. Responses including both convergence and open-passage solutions were classified according to the solutions given first. Few participants gave both target solution types before the hint or after the specific hints (3 before the hint, 12 after the nonspecific hint, 1 after the fortress hint, and 0 after the lightbulb hint). Solutions that did not fit into either of these target categories were coded as other solutions. Coding was blind to the language conditions of the source analogs. Each response was coded by three independent raters. The average pairwise reliability was 89% (Cohen’s \( \kappa = .82 \)). Consensus among the three coders was reached for all discrepancies. Categories of solutions given before the hint and after the nonspecific hint were combined to form the coding category for the total solution for each participant.

Before-hint and nonspecific-hint responses. Overall, convergence solutions were given more frequently than open-passage solutions before any hints were given (\( \chi^2(1) = 18.29, p < .0001 \)). The overall rates of open-passage and convergence solutions in before-hint responses were 13 and 47%, with 40% of solutions fitting into neither of these target categories. The nonspecific hint had its intended effect of increasing the overall target solution rate from 60 to 82% (or alternatively, halving the nontarget solution rate from 40 to 18%). Open-passage and convergence solutions were given at rates of 19 and 63%, respectively, preserving the strong advantage of convergence over open-passage solutions (\( \chi^2(1) = 21.83, p < .0001 \)).

Multiway contingency-table analyses were used to test the effects of the three language factors and their interactions on the type of solution given at each of the four solution stages. The three manipulated language variables were treated as fixed factors. The three levels of the outcome variable (open-passage, convergence, or other solution type) were partitioned into two orthogonal components of particular interest, each occupying one degree of freedom. The first component compared target (open passage and convergence) solutions to nontarget solutions. The second component compared the relative rates of open-passage and convergence solutions. Each four-way contingency table was analyzed using the hierarchical linear log-frequency testing procedure described in Experiment 1. The distribution of solution types for each of the eight language combinations is given in Table 2.

Table 3 shows the open-passage and convergence solution rates at each hint stage as a function of the language of each source story and target problem, and Table 4 shows solution rates as a function of the language matches or mismatches among the source and target analogies. As in Experiment 1, more target solutions (open-passage and convergence solutions combined) were given when the target problem was in English (71%) than when it was in Spanish (48%) both before the hint (\( G^2(1) = 5.31, p < .05 \)) and after the nonspecific hint (rates of 92 and 72%; \( G^2(1) = 7.04, p < .01 \)). No other language variable or interaction among language variables affected the overall rate of target solutions in before-hint or nonspecific-hint responses (\( p s > .20 \)).

The relative rates of open-passage and convergence solutions were affected by the languages of the source stories that suggested them. A higher rate of open-passage solutions relative to convergence solutions was observed when the Fortress story (open-passage analog) was in English than when it was in Spanish before the hint (\( G^2(1) = 7.20, p < .01 \)), as well as after the nonspecific hint (\( G^2(1) = 6.28, p < .05 \)). That is, when the Fortress story was pre-

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5 This advantage cannot be attributed to story order effects, because no order effect was observed with nearly identical materials (Francis & Wickens, 1996, Experiment 1).
presented in English, the open-passage solution rate was about one-half of the convergence solution rate; when it was presented in Spanish, the open-passage solution rate was less than one-seventh of the convergence solution rate. However, the complementary pattern of higher rates of convergence relative to open-passage solutions when the Lightbulb story (convergence analog) was in English than when it was in Spanish was not statistically reliable before the hint ($p = .20$) and was only marginally significant after the nonspecific hint ($G^2(1) = 3.52, p < .10$). The language of the target problem did not affect the relative rates of open passage and convergence solutions in either before-hint or nonspecific-hint responses ($ps > .10$).

The main comparisons of interest were the effects of language consistency between each source analogy and the target problem. When the languages of the Fortress story and the target problem matched, the rate of open-passage solutions relative to convergence solutions was no higher than when they mismatched ($p > .2, p > ...

### Table 2

<table>
<thead>
<tr>
<th>Language condition (Fortress, Lightbulb, and Ray Problem)</th>
<th>Before hint</th>
<th>Non-specific hint</th>
<th>Fortress hint</th>
<th>Lightbulb hint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Conv</td>
<td>Open</td>
<td>Conv</td>
</tr>
<tr>
<td>Eng–Eng–Eng</td>
<td>2</td>
<td>8</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Eng–Eng–Span</td>
<td>1</td>
<td>6</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Eng–Span–Eng</td>
<td>5</td>
<td>2</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Eng–Span–Span</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Span–Eng–Eng</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Span–Eng–Span</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Span–Span–Eng</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Span–Span–Span</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

*Note.* Eng, English; Span, Spanish; Open, open passage solution; Conv, convergence solution.

### Table 3

<table>
<thead>
<tr>
<th>Language condition</th>
<th>Before hint</th>
<th>Non-specific hint</th>
<th>Fortress hint</th>
<th>Lightbulb hint</th>
</tr>
</thead>
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<tr>
<td></td>
<td>Open</td>
<td>Conv</td>
<td>Open</td>
<td>Conv</td>
</tr>
<tr>
<td>Fortress story</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>.21</td>
<td>.43</td>
<td>.30</td>
<td>.57</td>
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<tr>
<td>Spanish</td>
<td>.04</td>
<td>.51</td>
<td>.09</td>
<td>.68</td>
</tr>
<tr>
<td>Lightbulb story</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>.11</td>
<td>.54</td>
<td>.13</td>
<td>.74</td>
</tr>
<tr>
<td>Spanish</td>
<td>.15</td>
<td>.40</td>
<td>.25</td>
<td>.52</td>
</tr>
<tr>
<td>Ray Problem</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>.19</td>
<td>.52</td>
<td>.25</td>
<td>.67</td>
</tr>
<tr>
<td>Spanish</td>
<td>.07</td>
<td>.41</td>
<td>.13</td>
<td>.59</td>
</tr>
</tbody>
</table>

*Note.* Open, open-passage solution rate; Conv, convergence solution rate. Responses containing both open-passage and convergence solutions were classified according to the solution given first.
Similarly, when the languages of the Lightbulb story and the target problem matched, the relative rates of open-passage and convergence solutions did not differ \((p > .5, p > .2)\). In contrast, the consistency between the languages of the Fortress and Lightbulb source stories did affect the relative rates of open-passage and convergence solutions. In matched-language conditions, there were 8 to 10 times as many convergence solutions as open-passage solutions. In mismatched conditions, the dominance of the convergence solution was diminished, with about 2 times as many convergence as open-passage solutions. This pattern was clear in both before-hint and nonspecific-hint responses \((G^2(1) = 6.47, p < .05; G^2(1) = 5.27, p < .05)\).

**Specific-hint responses.** In response to specific instructions to apply the Fortress story, open passage solutions were produced at a rate of 51%; In response to specific instructions to apply the Lightbulb story, convergence solutions were given at a rate of 81%. Thus, participants were better able to map the Lightbulb story and apply the convergence solution than to map the Fortress story and apply the open-passage solution \((\text{McNemar’s test}, \chi^2(1) = 20.63, p < .0001)\). The rate of specific-hint convergence solutions was similar to the 74% total convergence solution rate of Experiment 1. After specific hints, few inconsistent solutions were given. That is, participants gave few convergence solutions (eight total) in response to the Fortress hint and no open-passage solutions in response to the Lightbulb hint. For this reason, the specific-hint analyses were made using two response categories: The intended target solution for the hint given, and other (including other target).

Given the Fortress hint, open passages were more frequent when that story had been presented in English (62%) than when in Spanish (40%) \((G^2(1) = 4.33, p < .05)\), but the language of the Ray problem made no difference \((p > .2)\). (Compare to 68% in Francis and Wickens (1996, 1998).) There was a marginally significant trend for more open-passage solutions when the languages of the Fortress and Ray problems matched than when they mismatched (rates of 60 and 43%; \(G^2(1) = 2.74, p < .10\)). (Notably, as expected, the language of the Lightbulb story and the match between the Lightbulb story and Ray Problem made no difference, \(p > .5\).)
Given the Lightbulb hint, the tendency to give more convergence solutions when the Lightbulb story was in English (87%) than when in Spanish (75%) was not significant ($p > .10$), nor was the effect of language of the Ray Problem ($p > .2$) or the match between the Lightbulb story and Ray Problem ($p > .1$). The English Lightbulb solution rate was comparable to the 85% rate observed by Francis and Wickens (1996, 1998). (No other language variable, including those involving the language of the Fortress story affected the rate of convergence solutions after the Lightbulb hint, $p > .2$.)

Language proficiency effects. Within each language group, the data were too sparse to incorporate the full structure of the experimental design for inferential statistical analyses. However, some of the expected language-proficiency patterns were clear. Overall, the highly English-dominant group gave target solutions less often (46%) than did the other two groups (66 and 64%) before the hint, but the overall rates for the three groups did not differ after the nonspecific hint (81, 83, and 82%). Relative proportions of open-passage and convergence solutions did not differ across groups.

In contrast to Experiment 1, the effect of the target problem language on the overall target solution rates or on the relative rates of convergence and open-passage solutions did not vary across proficiency groups. The languages of the source stories, however, did affect the three groups differently. Specifically, the highly English-dominant group gave less target solutions than the other two groups when either source story was given in Spanish relative to when it was given in English (36, 56, 67% targets with Spanish Lightbulb story for highly English-dominant, slightly English-dominant, and equivalent-and-Spanish-dominant groups, respectively; 35, 63, 65% targets with Spanish Fortress story). When the Fortress story was in English, the advantage of convergence over open-passage solutions decreased with Spanish proficiency, but when it was in Spanish, the convergence solution advantage increased with Spanish proficiency. Effect of the language of the Lightbulb story on the relative rates of the two solution types did not differ across languages.

Given the hint to use the Fortress story, open passage solution rates were 31, 51, and 67% for the highly English dominant, slightly English dominant, and equivalent-and-Spanish-dominant groups, respectively. This effect was almost entirely accounted for by the higher solution rates when the Fortress story was in English than when it was in Spanish, which was more pronounced for the English-dominant groups. When the Fortress story was in English, solution rates were 58, 74, and 50% for the highly English dominant, slightly English dominant, and equivalent-and-Spanish dominant groups, respectively; when it was in Spanish, the corresponding solution rates were 7, 25, and 82%. Given the hint to use the Lightbulb story, overall convergence solution rates were 73, 77, and 91% for the three groups, but the overall better performance of the equivalent-and-Spanish-dominant group was not mediated by any detectable language effects. In contrast to the independent effects of the languages of the stories, the language consistency effects among the stories and target problem did not appear to differ across groups either before the hint or after any hint in the experimental sequence.

Discussion

The overall before-hint convergence solution rate (47%) was comparable to the rate observed in the before-hint responses of Experiment 1 (51%). Somewhat surprisingly, the change from fusing filaments with lasers to jarring filaments apart with ultrasound waves did not dramatically reduce the rate of before-hint transfer as it did in the Holyoak and Koh (1987) study. The advantage of convergence solutions over open-passage solutions was consistent with the higher content similarity between the Lightbulb story and the Ray Problem than between the Fortress story and the Ray Problem.

As expected, performance was affected by the languages of the two source stories and target problem, in that more analogous solutions were produced with English language materials than with Spanish language materials, and this advantage for English over Spanish was mediated in the expected direction by the participants’ self-rated relative proficiency in English.
and Spanish. Specifically, the language of the target problem affected the overall rate of target solutions, and the languages of the source stories affected the relative rates of the two target solution types. Students’ difficulty ratings for the three text passages concurred with these effects of language and proficiency level on performance.

Language consistency between the source and target analogies did not affect transfer detectably for the sample as a whole, nor did it appear to interact with proficiency group. Thus, the degree of between-language transfer was substantial and not differentiable from the degree of within-language transfer. In contrast, and perhaps surprisingly, language consistency between the two source stories affected the relative rates of the two solution types. When the languages of the two source analogies matched, the convergence solution dominated to a greater degree than it did when the two source analogies mismatched.

**Competition effects.** As will be explained, the advantage for language consistency between source stories has an interesting interpretation in terms of retrieval competition. The advantage of convergence solutions over open-passage solutions does not in and of itself constitute a competition effect. Arguably, the Lightbulb analogy is more similar in content to the Ray Problem than is the Fortress analogy, which leads to the expectation that the solution suggested by the Lightbulb story will be transferred more often than the solution suggested by the Fortress story. The competition effect is indicated by the greater advantage for the convergence over open-passage solution when both source stories were presented (68% vs 6% before hint) than when only one was presented (76% vs 59% before hint), as shown by Francis and Wickens (1996, 1998) using materials nearly identical to those of Experiment 2.

As expected, when the languages of the two source stories matched each other, the relative rates of convergence and open passage solutions (57 and 6% before hint) were similar to those observed by Francis and Wickens, with 8 to 10 times as many convergence solutions as open-passage solutions (both before the hint and after the nonspecific hint). In mismatched conditions, the dominance of the convergence solution was diminished (36% convergence vs 19% open passage), indicating that the alternative source analogs compete less when they are in different languages than when they are in the same language. Do the source analogs compete at all when their languages do not match? The answer to this question is not as clear, because the overall performance levels in the mismatched conditions of Experiment 2 and the noncompetitive condition of the previous study differ considerably. On the one hand, the open-passage rate is 53% of the convergence solution rate in mismatched language conditions and 78% in noncompetitive conditions, which would suggest some between-language competition. On the other hand, the absolute difference in both cases is 17%, suggesting no between-language competition. Between-language interference effects have been observed in other types of bilingual experiments. For example, in a bilingual part-set cueing experiment, presentation of members of a target category impaired generation of additional category members, even if they were to be generated in a different language (Peynircioglu & Gökşen-Erelcin, 1988).

After the nonspecific hint, the competition pattern in matched-language conditions was maintained (as in Francis & Wickens, 1996, 1998). However, after specific hints to use either the Fortress or the Lightbulb story, the language consistency between the Fortress and the Lightbulb story had no effect on solution patterns. Thus, the language-consistency effect on competition must have been restricted to the reminding process. This pattern could also stem from the restricted locus of the competition effect, which is shown to have its primary effect on reminding (thus before the hint), not mapping (Francis & Wickens, 1996, 1998). Another indicator that the competition is no longer operating at this stage is the significant positive association between producing open-passage solutions in response to the Fortress hint and producing convergence solutions in response to the Lightbulb hint (Cramér’s coefficient = .23; $\chi^2 = 4.831, p < .05$). If they were competing, a negative association would be expected (i.e.,
less people getting both or neither than expected by chance).

In sum, source analogies presented in different languages do not compete to the degree that items presented in the same language compete for analogical retrieval, and it is not clear that they compete at all. This pattern suggests that some of the observed competition occurs at language-specific levels.

METAANALYSIS OF EXPERIMENTS 1 AND 2

Is there any case for language-specificity in analogical transfer? To obtain an even more powerful test, data from Experiments 1 and 2 were pooled. The comparable convergence solution rates across experiments made a combined analysis reasonable. Experiment 2 data were sorted by the languages of the Lightbulb source analog and the Ray Problem only, collapsing across the language of the Fortress analog in order to make it compatible with Experiment 1 conditions. Thus, there were 207 cases in all, with 59 in the highly English-dominant group, 76 in the slightly English-dominant group, and 72 in the Equivalent-and-Spanish-dominant group. Table 5 shows the pooled before-hint and specific-hint solution rates for each language proficiency group in each language condition.

The four-way contingency table analysis described for Experiment 1 was repeated on the full set of data, using proficiency group, language of the Lightbulb story, and language of the Ray Problem as fixed-factor predictors and the solution type (convergence or other) as the outcome variable. Before the hint, the only statistically significant effects were the expected effects of proficiency level and language of the target problem, with the interaction between these two factors marginally significant. There was no indication of a language consistency effect or interaction of language consistency with proficiency group (ps > .2). After the hint (i.e., total responses), the expected effects of proficiency level and language of the target problem were again significant (though their interaction was not, p > .5). The effect of language consistency between the Lightbulb story and the Ray Problem was marginally significant in the expected direction ($G^2(1) = 3.41, p < .10$). Note that this test had 98% power to detect a 25% difference in solution rates between the matched and the mismatched language conditions and 82% power to detect a 20% difference. (Power estimates incorporated

<table>
<thead>
<tr>
<th>Solution stage</th>
<th>Language condition (Source–target)</th>
<th>Highly English dominant (N = 59)</th>
<th>Slightly English dominant (N = 76)</th>
<th>Equivalent and Spanish dominant (N = 72)</th>
<th>All groups combined (N = 207)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before-hint solutions</td>
<td>English–English</td>
<td>.67</td>
<td>.67</td>
<td>.64</td>
<td>.66</td>
</tr>
<tr>
<td></td>
<td>English–Spanish</td>
<td>.25</td>
<td>.43</td>
<td>.59</td>
<td>.43</td>
</tr>
<tr>
<td></td>
<td>Spanish–English</td>
<td>.39</td>
<td>.56</td>
<td>.50</td>
<td>.49</td>
</tr>
<tr>
<td></td>
<td>Spanish–Spanish</td>
<td>.27</td>
<td>.26</td>
<td>.71</td>
<td>.41</td>
</tr>
<tr>
<td>Total solutions</td>
<td>English–English</td>
<td>.93</td>
<td>.83</td>
<td>1.00</td>
<td>.92</td>
</tr>
<tr>
<td></td>
<td>English–Spanish</td>
<td>.50</td>
<td>.71</td>
<td>.88</td>
<td>.70</td>
</tr>
<tr>
<td></td>
<td>Spanish–English</td>
<td>.62</td>
<td>.83</td>
<td>.79</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td>Spanish–Spanish</td>
<td>.53</td>
<td>.74</td>
<td>.88</td>
<td>.73</td>
</tr>
</tbody>
</table>
the full design structure following methods in Wickens (1989).)

Examining each proficiency group separately, the advantage for having the Ray problem in English was significant before the hint for the two English-dominant groups, but not for the equivalent-and-Spanish-dominant group. After the hint, this effect was significant only for the highly English-dominant group. The effect of language consistency between the source and the target problem was marginally significant after the hint for the highly English-dominant and the equivalent-and-Spanish-dominant group ($p < .1$), but not for the slightly English-dominant group ($p > .9$), though the interaction between group and consistency effect was not significant in the four-way analysis ($p > .2$), so we cannot make the stronger claim that the effects differ across the three groups.

What can be made of these “marginally significant” source-target language-consistency effects? Is the language-consistency effect large enough to be important if it is real? Overall, after a specific hint, the analogous solution rate was 82% in matched-language conditions and 73% in mismatched-language conditions. Thus, the solution rate for mismatched source and target was nearly 90% of the rate for matched source and target. Intuitively, these effects are small and of minimal importance, but of course this assessment will depend more on consensus in the field than on one author’s interpretation.

**GENERAL DISCUSSION**

The present study begins to address high-level cognitive processes in the bilingual and to use bilingual performance to inform theories of high-level cognition. In Experiment 1, a standard analogical transfer procedure with previously established materials was adapted by translating the materials and manipulating the languages of the source and target analogies across participants. In Experiment 2, a relatively new and more sensitive analogical transfer procedure was similarly adapted. The degree of transfer across languages informs the nature of bilingual memory representations as well as the effects of input characteristics on analogical transfer.

Language consistency between source and target analogies had little or no effect on transfer. Nevertheless, the analysis shows that under certain conditions, retrieval processes are affected by consistency in input language between alternative source analogs. Language proficiency, in contrast, has clear effects on transfer. Across both experiments, the most important language factor in analogical transfer was proficiency in the language of the target problem. Whatever the language of learning, transfer performance was higher if measured in the dominant language, and this was not attributable to the relative difficulties of the source and target text passages in either language. The generality of this finding can be assessed only by further experimentation with other sets of materials. If, in fact, this finding is more generally true, it may reflect the different processing requirements of the story comprehension and problem solving tasks. Either the target problem language effect is due to output difficulty in the less-proficient language, or reading a problem and solving it in the less-proficient language makes a higher demand on processing resources, making reminding less likely and mapping more difficult. Language proficiency in the languages of the materials affected transfer both before and after the hint, though transfer was more sensitive to language proficiency level before the hint. The multinomial model analysis showed that this was because the retrieval process was more sensitive than the mapping process to language proficiency level.

Several studies have shown that input language is not the primary organizer of episodic memory representations of individual words or pictures. The results of the bilingual analogical transfer experiments are likewise inconsistent with such a representation for stories. The type of information accessed during analogical transfer is stored in a primarily meaning-based rather than an instance-based representation. The high degree of between-language transfer is clearly inconsistent with strictly language-specific retrieval or mapping. The high rate of between-language transfer, as high as 90% of the within-language transfer rate is most consistent with “language-general” retrieval and mapping, the
first of the four possibilities posed in the introduction.

From the perspective of the cognitive bilingual researcher, the high transfer between languages is perhaps not surprising. Research has shown that tasks dependent on “low-level” orthographic or phonological processing show little or no transfer across languages. For example, repetition priming for lexical decision response times does not transfer across languages (Cristoffanini, Kirsner, & Milech, 1986; Gerard & Scarborough, 1989; Kirsner, Brown, Abrol, Chadha, & Sharma, 1980; Kirsner, Smith, Lockhart, King, & Jain, 1984), and word fragment completion typically shows a low rate of priming and cued recall across languages (Basden, Bonilla-Meeks, & Basden, 1994; Durgunoglu & Roediger, 1987; Smith, 1991; Watkins & Peynircioglu, 1983). As the information or manner in which language is processed moves to a higher level, more transfer occurs, and for this reason, the underlying mental representations are thought to be more and more integrated. For example, tasks dependent on the semantic processing of individual words typically show a high degree of transfer across languages. Based on studies showing high rates of associative and translation priming of lexical decisions across languages (e.g., Chen & Ng, 1989; de Groot & Nas, 1991; Keatley & de Gelder, 1992; Kirsner et al., 1984; Schwanenflugel & Rey, 1986), high degrees of Stroop and Stroop-like interference across languages (e.g., Ehri & Ryan, 1980; Fang et al., 1981; Preston & Lambert, 1969; Smith & Kirsner, 1982), and equivalent semantic comparison times within and between languages (Caramazza & Brones, 1980; Dufour & Kroll, 1995; Popiel, 1987; Potter, So, Von Eckardt, & Feldman, 1984), the semantic systems of the two languages and semantic representations of pairs of translation equivalents are considered by most researchers in this area to be highly integrated, if not completely shared. (See Francis (1996, in press) for a more detailed review of these areas of research.) Few empirical tests of this claim exist beyond the word level, in part because of the difficulty of addressing these high-level processes. The logic of the field clearly suggests that the more complex the idea, the less dependent the representation on the language of input. It reasonably follows that the spontaneous use of high level information by bilinguals should not depend on the language in which it was learned, and in fact that is what the present study has shown.

Within the domain of analogical transfer research, the failure of the input-language mismatch to substantially reduce transfer is more surprising. Over the past 15 years, the analogical transfer literature has emphasized the context dependence of human learning. Seemingly trivial changes between the learning and potential application situations can greatly interfere with our ability to spontaneously retrieve and apply what we have learned. Even for transfer of learning that may not be specifically analogical, strong context effects are observed. For example, there is the oft-cited case of university students who, when given the curved tube and ball problem, failed to spontaneously apply principles they had learned in physics class (McCloskey, 1983).

The present findings further delineate the conditions under which “surface” similarities between source analogs and target problems affect analogical transfer. Previous research has shown that small changes in central objects, characters, or elements of a source analogy (Chen, 1995; Daehler & Chen, 1993; Holyoak & Koh, 1987; Keane, 1987; Ross, 1984), as well as broader changes in substantive context or semantic domain (Bassok & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer. Also, reductions in similarity between the context of presentation of the source and target analogies, such as experimental setting, description, experimenter, or time delay can have deleterious effects on transfer, primarily at the retrieval stage (e.g., Catrambone & Holyoak, 1989; Holyoak & Koh, 1987; Keane, 1987), have substantial effects at the reminding or retrieval stage of transfer.
affect transfer at either the retrieval or the mapping stage (Gick & McGarry, 1992). Similarly, effects of changes in the perceptual form of a source analogy, such as changes from a verbal story to a diagram (Gick, 1985) or changes in the input language (Experiments 1 and 2), may be undetectable.

More broadly, the relationship between language and thought is especially salient in the case of the bilingual, because fluent bilinguals learn new information through both of their languages. Is the input language merely a mechanism for achieving understanding, or does it shape the representation of that understanding in memory? Keeping other variables constant, the controlled language manipulations implemented in the present study demonstrate that the input language per se affects transfer only as a function of the bilingual’s proficiency in that language. Language consistency between learning and application situations (source and target analogies) did not significantly affect the degree of transfer, which suggests that the mental representations involved in the transfer process are language-free.

In the present study, every effort was made to separate the specific effects of language from those of culture and other contextual variables; however, outside the laboratory, bilinguals typically use their two languages in different contexts and to discuss different topics. Thus, in natural settings, changes in linguistic context are almost inextricably confounded with other situational changes. As explained, changes in semantic domain and changes in experimental setting substantially reduce transfer at the reminding stage. Similarly, changes in cultural context ought to have substantial effects on reminding. Of course, cultural context effects occur even within “monolingual” students, as exemplified by the surprisingly low transfer of learning from the school to the home or workplace. Clinical psychologists and medical professionals encounter similar difficulties in getting clients or patients to apply what they have learned in office visits to their everyday life events. Thus, further exploration of the effects of cultural context will be an important issue in examining bilinguals’ transfer in real-world learning situations. In general, we should expect reduced transfer across different-language situations in real life on purely nonlinguistic grounds. There is a circularity in the relationship between language and culture: The cultural or social context influences a person’s inclination to speak a particular language, and the use of a particular language may enhance or bring about a consistent cultural context. To the extent that using a particular language influences the cultural context, analogical transfer may be indirectly affected by language consistency. In and of itself, however, language consistency between learning and potential application situations is not an important determinant of analogical transfer in bilinguals.

APPENDIX A: MATERIALS USED IN EXPERIMENT 1

Source Analog: English Version (Adapted from Holyoak & Koh, 1987)

The Lightbulb. In a physics lab at a major university a very expensive lightbulb which would emit controlled quantities of light was being used in some experiments. The research assistant responsible for operating the sensitive lightbulb came into the lab one morning and found that the lightbulb no longer worked. The research assistant realized that she had forgotten to turn it off the previous night. As a result the lightbulb overheated, and the filament inside the bulb had broken into two parts. The surrounding glass was completely sealed, so there was no way to open it. The lightbulb could be repaired if a brief, high-intensity laser could be used to fuse the two parts of the filament into one. Furthermore, the lab had the necessary equipment to do the job.

However, a high-intensity laser would also break the fragile glass surrounding the filament. At lower intensities the laser would not break the glass, but neither would it fuse the filament. So it seemed that the lightbulb could not be repaired, and a costly replacement would be required.

The research assistant was about to give up when she had an idea. She placed several lasers in a circle around the lightbulb, and adminis-
tered low-intensity lasers from several directions all at once. The lasers all converged on the filament, where their combined effect was great enough to fuse it. Since each spot on the glass was only exposed to one low-intensity laser, the glass was left intact. There was a great relief that the lightbulb was repaired, and it was possible to successfully complete the experiment.

Source Analog: Spanish Version

El Foco. En un laboratorio de física en una universidad mayor, un foco muy caro que emitía controladas cantidades de luz se estaba usando en algunos experimentos. La asistente de investigaciones responsable de operar el sensitivo foco llegó una mañana al laboratorio y encontró que el foco ya no funcionaba. La asistente se dio cuenta de que se le había olvidado apagarlo la noche anterior. Resultó que el foco se había sobrecalentado, y el filamento adentro del foco se había roto en dos partes. El vidrio que le rodeaba estaba completamente sellado, y entonces no había manera de abrirlo. El foco se podría arreglar si un laser breve y de alta intensidad se pudiera usar para fusionar las dos partes del filamento a una. Además, el laboratorio tenía el equipo necesario para hacer el trabajo.

Un laser de alta intensidad también rompería el vidrio que rodeaba el filamento. A intensidades más bajas, el laser no rompería el vidrio, pero tampoco fusionaría el filamento. Así parecía que el foco no se podía arreglar, y una remplazación costosa se requeriría.

La asistente estaba al punto de rendirse cuando tuvo una idea. Ella puso varios lasers en un círculo alrededor del foco, y administraba lasers de baja intensidad de varias direcciones al mismo tiempo. Todos los lasers convergieron en el filamento, en donde su efecto combinado era suficiente para fusionarlo. Porque cada lugar en el vidrio solo se expuso a un laser de baja intensidad, el vidrio se quedó intacto. Hubo un gran alivio que se arreglara el foco, y fue posible completar el experimento con éxito.

Nonanalogous Story: English Version

(Adapted from Gick & Holyoak, 1980)

The Wine Merchants. One day a rich man found that his wine cellar was empty. So he sent out messengers to announce a generous offer. The first person to bring the rich man a barrel of wine would be given a brick of pure gold. However, the offer would expire at nightfall.

Two wine merchants heard the news. Each had a horse-drawn cart that was loaded with large barrels of wine. They both set out for the rich man’s palace at once. An hour before nightfall they came to a place where the bridge had been washed out by a raging river. The first merchant drove his horses and cart into the flood in a desperate attempt to reach the other side. But the horses were already exhausted and could not fight the current. The cart overturned, and the horses, wine, and driver were washed away.

The second merchant tried a different tactic. He poured the wine out of all but one of his barrels, and lashed them together to form a raft; then he loaded the one full barrel and a horse, and he climbed onto the raft. He set the raft adrift and floated downstream. In a few minutes the raft came to rest on the shore in front of the town where the rich man lived. The merchant disembarked, loaded the wine barrel on the horse, and led it to the rich man’s house. He arrived just as the sun was setting, and received the gold brick as a reward for his efforts.

Nonanalogous Story: Spanish Version

Los Comerciantes De Vino. Un día un hombre rico encontró que su bodega de vinos estaba vacía. Entonces mandó a unos mensajeros para anunciar una oferta generosa. La primera persona que le trajera al hombre rico un barril de vino se le daría un ladrillo de oro puro. Pero la oferta se acabaría al anochecer.

Dos comerciantes de vino escucharon la noticia. Cada uno tenía una carreta de caballos que estaba cargada con grandes barriles de vino. Los dos se pusieron en marcha hacia el palacio del hombre rico en seguida. Una hora antes del anochecer llegaron a un lugar donde el puente había sido arrasado por un río crecido. El primer comerciante llevó sus caballos y la carreta hacia la crecida en un intento desesperado por alcanzar el otro lado. Pero los caballos ya estaban agotados y no podían luchar contra la corriente.
The Ray Problem. Suppose that you are a doctor in charge of treating a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the tumor will spread throughout the body and the patient will die. The patient’s immune system is so weak that it cannot tolerate further drug treatment, but it is discovered that there is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a sufficiently high intensity, the tumor will be destroyed. Unfortunately, at this intensity the capillaries in the healthy tissue that the rays pass through on the way to the tumor will also be destroyed, causing uncontrollable hemorrhage. At lower intensities the rays will not harm healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with rays and at the same time avoid destroying any of the healthy tissue?

El Problema del Rayo. Suponga que Usted es un médico encargado de tratar a un paciente que tiene un tumor maligno en su estómago. Es imposible operar al paciente, pero a menos que se destruya el tumor, el tumor se va a extender por todo el cuerpo y el paciente se morirá. El sistema inmune del paciente está tan débil que no puede aguantar más tratamiento con drogas, pero se descubre que hay una clase de rayo que se puede usar para destruir el tumor. Si los rayos alcanzan el tumor al mismo tiempo a una intensidad suficiente alta, el tumor será destruido. Desafortunadamente, a esta intensidad los capilares en el tejido sano por los cuales los rayos pasan en camino al tumor también se destruirán causando hemorragia incontrolable. A intensidades más bajas, los rayos no dañarán el tejido sano, pero tampoco afectarán el tumor. ¿Qué clase de procedimiento se podría usar para destruir el tumor con los rayos, y a la vez evitar que se destruya el tejido sano?
and the general led his army to the head of that road. When all was ready he gave the signal, and the entire army charged down the open route. The army avoided passing over the mined roads and attacked the fortress with full strength. In this way, the general was able to capture the fortress and overthrow the dictator.

Open Passage Source Analog: Spanish Version

El General. Un pequeño país cayó bajo el poder de un dictador. El dictador gobernaba el país desde una poderosa fortaleza. La fortaleza se situaba en el medio del país, rodeada por grangas y pueblos. Había muchos caminos que conectaban la fortaleza con otras partes del país. Surgió un gran general que formó un numeroso ejército en la frontera y prometió capturar la fortaleza y liberar el país del dictador. El general sabía que si todo su ejército pudiera atacar la fortaleza a la vez, podría ser capturada. Sus tropas se posicionaron en el principio de uno de los caminos que llegaba a la fortaleza, listos para atacar. Sin embargo, un espía le trajo al general un reporte preocupante. El dictador sin escrupulos había puesto minas en cada uno de los caminos. El ejército no podía pasar sobre ellas sin peligro, porque cualquier fuerza detonaría las minas. Esto no sólo causaría la explosión del camino y lo haría intransitable, sino que el dictador destruiría muchos pueblos cercanos en represalia. Así que un ataque a la fortaleza parecía imposible.

El general, sin embargo, no se dio por vencido. El razonó que la fortaleza debía de tener una ruta de suministros. Esta ruta se tendría que mantener siempre abierto, debido a que el dictador necesitaba transportar sus propios tropas, trabajadores, y provisiones dentro y hacia la fortaleza. Con la ayuda del espía, descubrió cuál camino era la ruta de suministros, y el general condujo su ejército al principio de ese camino. Cuando todo estuvo listo, él dio la señal y todo el ejército se lanzó a través del camino abierto. El ejército evitó pasar por los caminos minados y atacó la fortaleza con todo su fuerza. De esta manera, el general pudo capturar la fortaleza y derrocar el dictador.

Convergence Source Analog: English Version (Adapted from Holyoak & Koh, 1987)

The Lightbulb. In a physics lab at a major university a very expensive lightbulb which would emit controlled quantities of light was being used in some experiments. The research assistant responsible for operating the sensitive lightbulb came into the lab one morning and found that the lightbulb no longer worked. The research assistant realized that she had forgotten to turn it off the previous night. As a result the lightbulb overheated, and two filaments inside the bulb fused together. The surrounding glass was completely sealed, so there was no way to open it. The lightbulb could be repaired if a brief, high-intensity ultrasound wave could be used to separate the two fused parts. Furthermore, the lab had the necessary equipment to do the job.

However, a high-intensity ultrasound wave would also break the fragile glass surrounding the filament. At lower intensities the ultrasound wave would not break the glass, but neither would it separate the fused parts. So it seemed that the lightbulb could not be repaired, and a costly replacement would be required.

The research assistant was about to give up when she had an idea. She placed several ultrasound machines in a circle around the lightbulb, and administered low-intensity waves from several directions all at once. The waves all converged on the filament, where their combined effect was great enough to jar apart the fused parts. Since each spot on the glass was only exposed to one low-intensity wave, the glass was left intact. There was a great relief that the lightbulb was repaired, and it was possible to successfully complete the experiment.

Convergence Source Analog: Spanish Version

El Foco. En un laboratorio de física en una gran universidad, se estaba usando en algunos experimentos un foco muy caro que emitía cantidades controladas de luz. La asistente de investigaciones responsable de operar el sensitivo foco llegó una mañana al laboratorio y encontró que el foco ya no funcionaba. La asistente se dió cuenta de que se le había olvidado apagarlo la
noche anterior. Resultó que el foco se había sobrecalentado, y dos filamentos dentro del foco se habían fusionado. El vidrio que le rodeaba estaba completamente sellado, y entonces no había manera de abrirllo. El foco se podría arreglar si una onda de ultrasonido breve y de alta intensidad se pudiera usar para separar las dos partes fusionadas. Ademáis, el laboratorio tenía el equipo necesario para hacer el trabajo.

Una onda de ultrasonido de alta intensidad también rompería el vidrio que rodeaba el filamento. A intensidades más bajas, la onda de ultrasonido no rompería el vidrio, pero tampoco separaría las partes fusionadas. Así parecía que el foco no se podía arreglar, y una replamización costosa se requeriría.

La asistente estaba a punto de rendirse cuando tuvo una idea. Puso varias máquinas de ultrasonido, en un círculo alrededor del foco, y el equipo necesario para hacer el trabajo. El foco se podría arreglar, y fue posible completar el experimento con éxito.

Target Problem: English Version

See Target Problem: English Version, Appendix A.

Target Problem: Spanish Version

See Target Problem: Spanish Version, Appendix A.

REFERENCES


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