Memory & Cognition
2003, 31 (2), 221-230

Does analogical transfer involve a term-to-term alignment?

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According to dominant models of reasoning by analogy, analogical transfer requires subjects to first define a full one-to-one correspondence between the base and the target problems. Accordingly, these models predict that if there is a cross-mapping between the base and the target (cross-mapping exists when similar or identical elements in the base and the target play different roles), the time spent transferring a property from the base to the target will be greater. The present results are inconsistent with this prediction. Indeed, if the mapping task is more difficult in the cross-mapping condition than in the control condition, the time needed to make the transfer is not affected by the presence of a cross-mapping. Consequently, we conclude that the mapping phase is not a necessary condition for transfer.

According to dominant models of reasoning by analogy (Falkenhainer, Forbus, & Gentner, 1989; Holyoak & Thagard, 1989; Keane, Ledgeway, & Stuart, 1994), analogical transfer consists of a series of phases described as sequential: (1) encoding the source, (2) encoding the target, (3) if useful, retrieving an applicable source analogue from memory, (4) finding a mapping (i.e., a set of correspondences between source and target elements), and (5) deriving inferences based on the mapping.

Among these different phases, most authors agree that mapping is the crucial one and that this phase is specific to reasoning by analogy. During the mapping phase, the comparison of the base and the target is accomplished by a process of alignment of structured representations. This process of structural alignment attempts to place two representations in correspondence so that they form the maximal globally consistent match. The importance granted to this phase follows directly from the definition of analogy: An analogy is defined as a configural similarity based on systematic role correspondences. In the ideal case in which the structural correspondence is perfect, the analogy is akin to an isomorphism, and all isomorphisms are associated with a set of one-to-one correspondences that become explicit when the mapping is performed. In this case, it is generally agreed that the mapping process is a local-to-global type of process that enables global correspondences to emerge from the combination of local correspondences that abide by formal, essentially structural constraints (Goldstone, 1994b; Holyoak & Thagard, 1989; Markman & Gentner, 1993; Medin, Goldstone, & Gentner, 1993).

We thank Louis Bourrelly, André Diderjean, Évelyne Cauzinille, Cheryl Frenck-Mestre, and two anonymous reviewers for helpful comments on an earlier version of this manuscript. Correspondence concerning this article should be addressed to T. Ripoll, LPC, Université de Provence, 29 Avenue Robert Schuman, 13621 Aix-en-Provence Cedex, France (e-mail: ripoll@newsup.univ-mrs.fr).

Although this way of conceiving of analogy is fully consistent with the definition of analogy, we think that the importance granted to mapping (and structural alignment) and the sequential approach traditionally adopted in the corresponding models leads to some questionable hypotheses (see Ross & Bradshaw, 1994, on this point). One such hypothesis is that target encoding and, thus, the representation that a subject builds before structural alignment are not determined by prior encoding of the source, so the source only has a potential effect on target processing during or after the comparison. Another hypothesis, directly related to the first, is that analogical transfer necessarily implies prior alignment—that is, term-to-term correspondences between source and target properties.

Even if some authors state that the entire analogical process need not be performed in a strictly serial fashion (Eskridge, 1994; Holyoak, Novick, & Melz, 1994), all theoretical approaches and all the main models (SME [Falkenhainer et al., 1989], ACME [Holyoak & Thagard, 1989], and IAM [Keane et al., 1994]) assume that analogical transfer or analogical inferences can be derived only once the mapping phase has ended. The fact that analogical transfer intervenes after the mapping phase is a direct consequence of hypotheses made at both the computational and the algorithmic levels (Keane et al., 1994). Because the process of deriving candidate inferences is essentially one of structural completion (Bowdle & Gentner, 1997), these models must find a global mapping between the source and the target before deriving candidate inferences: "SME computes structural match first, and then uses this structured match to derive candidate inferences" (Falkenhainer et al., 1989, p. 43).

The empirical study presented here is based on an alternative view whereby subjects extract useful source properties very early during target encoding, before the term-by-term comparison begins. The source could therefore have an impact on the target representation in a way other than via the term-to-term alignment of the local

properties of the two analogous situations that are being compared. Let us now describe these possible relations between encoding, mapping, and transfer.

How Are Encoding, Mapping, and Transfer Related?

We hypothesize that subjects extract high-level information from the source that constrains the target representation-building process very early in the process (Ripoll & Coulon, 2001). We call this early source effect *analogical encoding.* In this view, an important part of the process of reasoning by analogy begins before mapping.

This hypothesis is meaningful if one agrees that base processing provides some global information (e.g., categorical information) that can constrain target encoding very early and, consequently, affect the whole analogical reasoning process. As soon as a subject is informed of the existence of an analogy between two problems (case of didactic analogies), it is reasonable to assume that the information extracted from the source will have a very early impact on the building of the target representation, before any search for local correspondences between base and target properties. For example, if a student is given an analogy between two problems and if the base is identified as a thermodynamic problem, the early conceptualization of the target will be strongly constrained by the categorical information extracted from the source: During target encoding, the student will search for information that is relevant to the context of thermodynamic problems.

This *top-down process* from the source to the target before structural alignment (i.e., analogical encoding) requires the conjunction of two important properties that are absent in current models of analogy. The first property is that the architecture of the model must allow for *target contamination* by the source in ways other than the mapping process. This property appears to be present only in the LISA model (Hummel & Holyoak, 1997). In LISA, source properties modify the activation level of target properties (and thus their accessibility) and directly constrain the mapping process. In the architectures of other models, source and target representations are completely independent and fixed. Consequently, target representation can be modified only after the mapping process.

The second property is that source encoding allows for the extraction of high-level global properties that play an active role during the building of the target representation. A typical example of this type of property is categorical representation, whether this is the result of visual stimulus processing, a word problem, or an everyday experience. When categorical information is extracted from the source, it can act as a processing structure whose main functions are to make inferences (Murphy & Ross, 1994), attribute properties to the objects relevant to the category (Barsalou, 1983), and select the properties of the categorized object that are relevant to the context of the initial categorization (Barsalou, 1982). In the field of reasoning by analogy, one can consider that the source gives the subjects the categorical information they use to elaborate a target representation. In this sense, an important part of the analogical process begins before mapping, during what we previously called *analogical encoding.*

In the extreme case, the information extracted from the source is a schema that can be directly used to solve the target (Gick & Holyoak, 1983; Reeves & Weisberg, 1994). But in this case, are we still in the field of reasoning by analogy? The answer to this question depends on the definition of analogy that we adopt, but it is clear that if subjects have a previously stored schema, the source, taken as a specific case, is no longer useful for solving the target problem. Nevertheless, between abstract and richly structured schematic representations and more specific representations (source knowledge), there are many intermediate levels of abstraction that can play an important role in analogical reasoning while still fulfilling a crucial function at the specific source knowledge level. Schunn and Dunbar (1996) obtained empirical results that are consistent with this theoretical framework. They showed that source knowledge (a simulated biochemistry problem) enabled activation of a concept (here, the concept of inhibition in biology), which implicitly guided the subjects during target solving even though they probably had not made an even partial mapping between the source and the target. In this situation, the concept of inhibition is a global property inferred from the source, which is very different from a schema, because it describes the source very roughly without giving precise information on the system of complex relations in each analogical case.

In our theoretical framework, the source fulfills two important functions before structural alignment. First, during analogical encoding, the source can constrain the accessibility of target properties and, thereby, reduce the quantity of information taken into account during the mapping, leading to a potential decrease in the computational cost of this expensive process. Second, if the source constrains the initial target representation before mapping, it is possible, especially when the target problem needs a small number of solving steps, that the source allows for analogical solving of the target at the very time when no local source–target correspondences have been made. This situation is more probable in the case of insight problems (Holyoak & Barnden, 1994; Metcalfe & Wiebe, 1987), for which a direct and rapid solution is possible whenever the target representation is correct. In other words, a term-to-term alignment may no longer be required for solving analogical problems. This second hypothesis lies at the core of the present work.

Relations Between Transfer Time, Mapping Time, and the Presence of Cross-Mapping

In the prevailing approach to reasoning by analogy, transfer time is tightly linked to mapping time, even if the transfer involves some problem-specific adaptation processes (after the mapping phase; Holyoak et al., 1994). In theory, any mapping-time increase should lead to a concomitant transfer-time increase of greater or equal magnitude, given that mapping occurs prior to transfer (Markman, 1997). Consequently, the presence of cross-mapping—elements common to the source and the target that play

different roles, as in the two analogical sentences, *The cat catches the mouse* and *The dog catches the cat*—should cause an increase in transfer time because of the difficulty brought about by cross-mapping when two analogous situations have to be aligned (Gentner & Toupin, 1986; Ripoll, Bourrelly, Antoni, & Pélissier, 2000; Ross, 1987).

Recall that during the mapping stage, predicates and objects are aligned. In the case of a cross-mapping, predicate matching and object matching compete by giving two different, concurrent interpretations (relational interpretation and object interpretation for SME) or a single mixed interpretation (for ACME). As a consequence of these opposing pressures, the time needed to find the best correspondences increases. Because these models assume that transfer can be made only after prior alignment of objects and predicates, target solving will be more difficult when the two analogues are cross-mapped.

In contrast, because we hypothesize that high-level information inferred from the source may affect the target representation very early, it is possible (see the previous section) that subjects use this high-level source information to understand or solve the target situation. In this case, a source with cross-mapping could lead to an analogical solution to the target without causing a significant rise in transfer time. Proving this amounts to demonstrating a dissociation between mapping time and analogical transfer time, in such a way that only mapping time, and not transfer time, is affected by the presence of a cross-mapping. To do so, we conducted two experiments in which the same material was used, one with a source–target analogical transfer task in which subjects had to complete an incomplete target sentence by drawing upon their knowledge of an analogical source sentence, and one with a mapping task in which they had to indicate what word in the source (*object* in predicate-calculus formalism) corresponded to a given word in the target. These two different tasks can be considered as two modes of analogical reasoning, but the important thing here is to recall that, according to classical models of reasoning by analogy, mapping is included in the transfer task, the reverse not being necessarily true.

EXPERIMENT 1A
Transfer

In this experiment, our aim was to show that subjects can make use of a source situation to process an incomplete target without there being a significant increase in target processing time due to cross-mapping. Consequently, we predicted that there would be facilitation due to the analogical source and that this facilitation would be equal in all cases, regardless of the presence or absence of cross-mapping. Specifically, the subject's task was to use an already-read source sentence to fill in missing information in an incomplete target sentence, knowing that the source and the target were analogous.

Method

Subjects. Thirty subjects from the University of Provence participated for course credit. The entire experiment took about 25 min.

Material. Eighteen simple sentences were generated, 6 of which were target sentences and 12 of which were source sentences. Each target sentence had 2 corresponding source sentences, 1 without a cross-mapping sentence and 1 with a cross-mapping sentence. The target sentence to be completed by the subject contained two or three objects and one or two relational predicates. The 2 source sentences corresponding to a given target were strictly the same, except for the cross-mapping (lion/gorilla in the example below). But the syntactic structure of the two sources always differed from that of their target so as to prevent the sentence structure from supplying a surface cue that would facilitate the transfer.

Target sentence: **A lion** will not be afraid of _____ even if it looks ready to attack.
Without cross-mapping source sentence: Even if it acts aggressively, **a gorilla** will never scare an elephant.
Cross-mapping source sentence: Even if it acts aggressively, **a lion** will never scare an elephant.

Design. Three experimental conditions were set up: a without cross-mapping condition, a cross-mapping condition, and a control condition. In the control condition, the subjects processed the target without having read the source. Each subject processed all the target sentences and was tested in all three experimental conditions but saw each target sentence only in one experimental condition (i.e., two target sentences per condition). The sentence presentation order was random.

Procedure. The experiment was computer driven. The source sentence was displayed on the screen. After 5 sec, the source disappeared, and the target sentence appeared in its place. To prevent interindividual differences in reading time from skewing the transfer-time data, the pace for displaying word groups in the target sentence was controlled. The pace for displaying word groups was defined on the basis of the results of a pretest aimed at assessing target reading speed. When the last word of the target appeared, the timer was started. As soon as the subjects found the words to complete the target sentence, they pressed a key, and the timer was stopped. Immediately after pressing the key, they said the words out loud.

The subjects were informed in advance that the source and the target had similar meanings and that several different solutions were possible. In the above example, answers such as hunter, tiger, and rhinoceros would have been considered incorrect, because they do not comply with the relations present in the source, whereas answers like ant, gazelle, and hare would be considered correct. The subjects had to complete the target as quickly as possible, but they were told to choose the best solution given that the two sentences were analogues. When there was no source (control condition), they were instructed to complete the target sentence in a meaningful way. A preliminary practice phase on three sentences (one per condition) familiarized the subjects with the task. The dependent variable measured was response time.

Results and Discussion

Although the relevant dependent variable here was response time, response accuracy was also checked. An answer was considered correct if the subject completed the target with words that made the target sentence analogous to the source sentence. The percentage of correct answers was very high for all sources (93% in the without cross-mapping condition, 88% in the cross-mapping condition, and 89% in the control condition; $\chi^2 < 1$, $p > .10$).

For the response time analyses, the results always refer to both correct and incorrect responses. This choice was motivated by the fact that there was no statistical relation between time and correctness. Consequently, variance analyses conducted only with correct responses were very similar to the variance analyses reported here. Furthermore,

we present only the analysis of variance with subjects as the random factor, given that the analysis of variance with item as the random factor was fully consistent. There was a main source effect on response time [$F(2,58) = 9.37$, $MS_e = 12.784$, $p < .0005$]. Response time was significantly longer in the control condition (10.12 sec) than in the conditions in which a source was previously read by the subjects [without or with cross-mapping conditions; 6.67 sec; $F(1,58) = 18.64$, $MS_e = 12.784$, $p < .0001$]. In contrast, there was no difference between the without cross-mapping (6.82 sec) and the cross-mapping (6.52 sec) conditions [$F(1,58) = 0.10$, $MS_e = 12.784$, $p = .75$].

The fact that the subjects in the conditions with a source responded more quickly than the subjects in the control condition clearly shows that the former subjects made use of the source to complete the target sentence. On the other hand, contrary to predictions based on the classical approach, the cross-mapping did not pose any particular problems, even though the source was indeed used to facilitate the analogical transfer.

EXPERIMENT 1B
Mapping

One might object to the above experiment by saying that the cross-mapping did not jeopardize the transfer, simply because the cross-mapping used did not make the term-to-term alignment of the two analogous situations more difficult. This objection is all the more justified because some studies have shown that the difficulty of a mapping is not strictly determined by whether the structural and the surface properties are mutually supportive (Bassok, Wu, & Olseth, 1995; Ripoll et al., 2000; Ross & Kilbane, 1997). In particular, when subjects are experts in a domain, they manage to map the elements of two analogous situations despite semantic dissimilarity. Consequently, the aim of this experiment was precisely to verify that the cross-mapping used here truly did increase the difficulty of finding local correspondences. This control is crucial, because we can legitimately expect a longer transfer time in a cross-mapping condition only once we have shown that cross-mapping does in fact make the alignment more difficult.

Method

Subjects. Twenty subjects from the University of Provence participated in the experiment.

Material. The material was the same as that in Experiment 1A, except that the target sentence did not have a missing element. This was done so that the alignment process could be accurately assessed independently of the other processes necessarily involved in searching for a missing element.

Design. The same experimental design as that in Experiment 1A was used, except that there was no control condition.

Procedure. The display mode for the source and the target was strictly the same as that in Experiment 1A. When the last word of the target appeared on the screen, the target element to match appeared in boldface characters. The timing started at that point. As soon as the subject managed to identify the corresponding source element, he or she pressed a key that stopped the timing. Immediately afterward, the subject responded aloud. The dependent variables collected were response time and the answer given.

Results

An answer was considered correct if the subject stated the corresponding element of the source. Although the number of correct answers was greater in the without cross-mapping condition (97%) than in the cross-mapping condition (85%), this difference was nonsignificant ($\chi^2 = 1.64$, $p < .20$). However, matching time was significantly greater in the cross-mapping condition (6.68 sec) than in the without cross-mapping condition [3.85 sec; $F(1,19) = 13.92$, $MS_e = 5.738$, $p = .001$].

Discussion of Experiments 1A and 1B

The main result of Experiment 1B is in line with the predictions of classical models, as well as with the empirical data collected in earlier studies (Gentner & Toupin, 1986; Novick & Holyoak, 1991; Ross, 1987, 1989). Nevertheless, these earlier results, taken together with the results of Experiment 1A, suggest that the use of a source to solve an analogous target does not involve a preliminary term-to-term alignment. More concretely, they clearly show that mapping can be affected by cross-mapping, even if transfer is not.

If we agree that reliance on a source that facilitates the analogical transfer involves a term-to-term alignment of local properties and if this alignment takes more time in the presence of cross-mapping, we should have obtained longer target completion times in the cross-mapping condition than in the without cross-mapping condition. Yet, although the subjects clearly used the source to process the target, the cross-mapping was not a hindrance. This proves that an analogical transfer can be constrained by knowledge of the source even when no term-to-term alignment between the local properties of the two analogous situations takes place.

One could nevertheless object to this interpretation by saying that the subjects may not actually have used the source in the present case but relied, instead, on a general schema previously extracted from it. If this is true, then, strictly speaking, the subjects did not reason by analogy; they activated and then applied a schema to identify the missing target element. The validity of our hypothesis would be limited here to the case in which subjects have access to a schema already stored in memory that is activated by the source the experimenter presents.

Although this objection is legitimate, there are at least three considerations that weaken it. First, the source sentences used in this experiment were not based on an implicit preestablished schema. A questionnaire administered to see whether it was possible to associate these sentences to a known expression, idea, or concept (saying or proverb) showed that such associations were very rare. Second, a general schema is hardly ever induced following the presentation of a single example (Cauzinille-Marmèche & Didierjean, 1999; Gick & Holyoak, 1983) but is, rather, the outcome of the comparison of two analogous situa-

tions (Catrambone & Holyoak, 1989; Medin & Ross, 1989), often prompted by the experimenter (Reeves & Weisberg, 1994). Third, because we are clearly dealing here with the analogical understanding of an (incomplete) target based on a (complete) already processed source, this experimental situation does not differ fundamentally from the ones traditionally studied in empirical research on analogy. Hence, any objection concerning whether the source was actually used in this experiment could also be directed at classical experiments conducted in this field: As a rule, the existence of reasoning by analogy is inferred from the fact that subjects who have already processed the source achieve higher performance than those who process the target directly. At a more general level, what has long appeared to be a fact (mandatory mapping prior to any analogical transfer) should be seen instead as a full-fledged hypothesis. This hypothesis has rarely been tested in the empirical analogy research.

In our minds, the objection that subjects simply apply a general schema following source processing does, nonetheless, raise a crucial theoretical issue. It is traditionally agreed that schematic representations cannot be regarded as a prerequisite to reasoning by analogy (Reeves & Weisberg, 1994). Clearly, if subjects possess a sufficiently precise schematic representation, recourse to an analogous case would not really be very useful, and the analogy would lose most of its heuristic value (Gentner, 1989; Gick & Holyoak, 1983). At best, the analogous source would supply cues that facilitate schema activation. However, we contend that between highly abstract, decontextualized schematic representations and representations that code the specific features of a case in memory (for instance, representations in terms of different types of predicates, objects, and attributes, as have classically been adopted in models of analogical reasoning) there is room for representations at an intermediate degree of abstraction. Such intermediate representations may play a substantial role in analogy processing (for a detailed description of these intermediate levels of abstraction and their role in analogous problem recall, see Ripoll, 1998).

The purpose of Experiment 2A was to show that although the subjects did not perform a term-to-term alignment before transfer in Experiment 1, they did more than simply instantiate a very general schema to solve the target problem.

EXPERIMENT 2A

If subjects were to extract a general schema from the source and then instantiate and adapt it to the target, the source's surface properties—object properties specific to each analogical case—should not have had an impact on what was transferred. If this turned out to be true, we could conclude that it was not the source that was directly used to solve the target, but the schema that was extracted from it. If, on the contrary, the subjects were to complete the target in a way that showed that they had been influenced by the source's surface properties, it could hardly be contended that they had merely instantiated a general schema. We should conclude, instead, that the subjects had in fact made use of the source itself and that they had indeed reasoned by analogy.

To test this hypothesis, the same paradigm as that in the first experiment was reused with new sentences generated in such a way that it would be possible to assess the effect of the source's surface features on target processing. In particular, in addition to the source cross-mapping and without cross-mapping sentences, we added new sentences called *interdomain* sentences. These were analogous to the other source sentences, but the semantic domain to which they referred was different from the domain of the previous sources (with and without cross-mapping). In the example given in the Materials section, the interdomain source sentence (*A trap-door spider, even a small one, will always be more imposing than a termite*) had exactly the same structure as the other source sentences of the same item (*An elephant, even a small one, will always be more imposing than a gazelle*), but their surface properties (object properties) were very different. If, as expected, subjects rely on the surface properties of the source to process the target, target completion under intradomain (without cross-mapping and with cross-mapping) and interdomain conditions, although structurally equivalent, should be semantically different. In this case, we would predict that the words they would choose to complete the target would be semantically tainted by the source's surface properties. In the example, subjects would more often choose to complete the target sentence with words related to insects, for any kind of target.

Method

Subjects. Thirty-two subjects from the University of Provence participated in the experiment .

Materials. The materials consisted of 32 sentences, 8 of which were target sentences and 24 of which were source sentences. Each target sentence had 3 corresponding source sentences: a without cross-mapping source sentence and a cross-mapping source sentence from the same semantic domain (intradomain) and an interdomain source sentence from a different semantic domain. The intradomain source sentences (with and without cross-mapping) differed by one element: the word that was cross-mapped. Likewise, the intradomain and interdomain source sentences were strictly analogous, and their syntactic form was identical. They differed only in their surface properties: Concretely, the differences pertained to the two or three objects in the sentence, not to the predicate that related them to each other. On the other hand, the syntactic form of the source and the target sentences was always different.

The semantic *distance* between the inter- and the intradomain sources was checked a posteriori. This was done by presenting the subjects with all of the objects in the intra- and interdomain sources associated with a given target (in the example below, elephant, gazelle, wild boar, trap-door spider, and termite) and asking them to sort them into two categories of their choice. The interdomain source words (trap-door spider and termite) were systematically sorted into one category, and the intradomain source words into the other (elephant, gazelle, and wild boar).

Target sentence: Although quite small, _____ , a wild boar will feel big.
Without cross-mapping source sentence: An elephant, even a small one, will always be more imposing than a gazelle.

Cross-mapping source sentence: An elephant, even a small one, will always be more imposing than a wild boar.
Interdomain source sentence: A trap-door spider, even a small one, will always be more imposing than a termite.

Design. A single experimental factor with four levels was manipulated and used to define four experimental conditions (control, cross-mapping, without cross-mapping, and interdomain). Each subject processed all the target sentences and underwent all the experimental conditions but saw each target only in one experimental condition. The sentence presentation order was random.

Procedure. The source and target display mode was strictly identical to that used in Experiment 1A.

Results and Discussion

Note that, in the control condition, response time was below that observed in the previous experiment. This was due to the fact that the targets generated for this experiment were different from the ones used in Experiment 1. More important for our purposes here, a main effect of the type-of-source factor was found again [$F(3,93) = 6.88$, $MS_e = 9.9$, $p < .0005$]. Response time was significantly shorter in the conditions with a source (7.17 sec) than in the control condition [10.08 sec; $F(1,93) = 20.46$, $MS_e = 9.9$, $p < .0001$]. In contrast, no significant difference was noted between the without cross-mapping (7.12 sec), cross-mapping (7.36 sec), and interdomain (7.03 sec) conditions. In particular, the cross-mapping and without cross-mapping times were not significantly different statistically [$F(1,93) = 0.98$, $MS_e = 9.9$, $p = .79$].

We coded the subjects' answers according to the semantic properties of the element they proposed to complete the target. When the element was from the same semantic domain as the intradomain sources, it was assigned a score of +1 (for Sentence 1, e.g., squirrel, rabbit, or squirrel monkey). When the element was from the same semantic domain as the interdomain source, it was assigned a score of −1 (e.g., flea, beetle, cockroach, or ant). When the answer was incorrect (i.e., did not make an analogous sentence) or was from neither of the semantic domains of the intra- and interdomain sources, it was assigned a score of 0 (e.g., hunter, smaller animal, or blade of grass). The scoring was double-blind, and the agreement rate across scorers was 98%.

With the data coded in this way, we obtained a highly significant main effect of the type-of-source factor [$F(3,93) = 17.05$, $MS_e = 0.351$, $p < .0001$]. In addition, the average score in the intradomain conditions (.617) differed significantly from that in the interdomain condition [−.281; $F(1,93) = 17.22$, $MS_e = 0.351$, $p < .0001$]. In contrast, the without cross-mapping (.656) and cross-mapping (.578) scores did not differ statistically from each other [$F(1,93) = 0.28$, $MS_e = 0.351$, $p = .79$]. Finally, the average control score (.156) differed significantly from each of the conditions with a source.

The results of Experiment 1A were replicated here: Although the subjects did, in fact, make use of the source to complete the target, they were not disrupted by the presence of cross-mapping. Above all, we have shown here that the source's surface properties strongly constrained the answers given by the subjects. In this light, one can hardly contend that the transfer that took place was not analogical. If we accept the distinction proposed by Holyoak (1984) between schema-based problem solving and analogy-based problem solving, we must agree that the subjects used the analogy-based reasoning mode, with the specific properties of the source (its surface properties) having a notable impact on the transfer. The possibility that the subjects simply instantiated a general schema extracted from the source is not compatible with the large impact of the source's surface properties. Finally, it should be noted that the principal indicators of genuine reasoning by analogy were present here: facilitation of target processing when a source was proposed first and an effect of the source's surface properties on the type of transfer.

EXPERIMENT 2B
Mapping

Like Experiment 1B, this experiment was designed to ensure that cross-mapping could actually hinder subjects during term-to-term alignment.

Method

Subjects. Thirty-two subjects from the University of Provence participated in the experiment.

Material. The materials were identical to those used in Experiment 2A, except that, as in Experiment 1B, the targets did not have to be completed.

Design and Procedure. The design and the procedure were the same as those in Experiment 1B.

Results and Discussion

Answers were considered correct when the subject stated the corresponding source element. The percentage of correct answers (85%) was the same in the two experimental conditions. However, matching time was significantly longer in the cross-mapping condition (7.11 sec) than in the without cross-mapping condition [3.90 sec; $F(1,24) = 23.80$, $MS_e = 5.396$, $p = .01$].

The results of Experiment 1B were replicated, and the expected effect of cross-mapping in a matching task was obtained.

GENERAL DISCUSSION

According to prevailing models of reasoning by analogy and similarity, processing during the mapping phase is said to occur in two stages. In the first, all possible local correspondences are generated between base and target elements. In the second, local correspondences are coalesced into global correspondences that involve large sets of local elements. Global correspondences cannot emerge until local properties have been compared, and it is only at that point in the process that it is possible to transfer the source properties to the target. Consequently, transfer of properties from the base to the target cannot be accomplished before local correspondences are generated: "Furthermore, the postmapping process of inference must use

the set of correspondences established by the mapping process in order to generate plausible inferences about the target" (Holyoak et al., 1994, p. 114).

Not too long ago, a few authors raised the objection that this type of model of analogical reasoning, based solely on a single processing mode, is too rigid to account for the clever and adaptive nature of human cognitive functioning (Bassok & Medin, 1997; Hummel & Holyoak, 1997; Love, Rouder, & Wisniewski, 1999; Wisniewski & Bassok, 1999). Although hypothesizing that multiple processes underlie similarity and analogy processing detracts from the parsimony of which current theories can boast, we are forced to recognize that doing so is very useful for establishing a general theoretical framework capable of coherently integrating problematic data.

Viewed from this angle, the data collected here support the hypothesized involvement of multiple processes in reasoning by analogy. We have seen, first, that subjects did in fact make use of their knowledge of the source to facilitate the processing of an incomplete target and, second, that they probably did not map the source and the target to draw the necessary inferences for target processing. At least for certain types of analogy, then, mapping is not a prerequisite to transfer. Obviously, one could still refuse to see our experimental situation as an analogical one. This argument seems difficult to defend, however, insofar as all the characteristics of an analogical situation were present: The source facilitated target processing, the target and the source were structurally similar, and the surface properties had an impact on the type of analogical transfer.

On the other hand, we do not think that our results challenge the classical view of reasoning by analogy in a fundamental way. They merely argue for a more constructivist approach to similarity and for the existence of polymorphous modes of similarity and analogy processing. In arguing for a constructivist approach, we mean that, when representations of to-be-processed stimuli are built by subjects, they should be seen as relying on many deductive or inductive inferences, as well as on their general semantic knowledge. A case in point is the processing of natural language utterances. It is clear that representations built from texts may turn out to be much richer than a conventional breakdown into predicates, objects, and attributes, as is generally found in models of reasoning by analogy (Ripoll & Coulon, 2001). Traditionally, such models simulate this process by postulating a source- and target-encoding process that roughly corresponds to what Kintsch (1992) called the *textbase level*. The textbase level includes a propositional description of the explicit text. However, some of the older work in the field of text comprehension (Bransford & Franks, 1971; Collins, Brown, & Larkin, 1980), as well as a number of more recent studies (Graesser, Singer, & Trabasso, 1994; Kintsch, 1992; McKoon & Ratcliff, 1992), have shown that subjects build highly abstract representations, sometimes inferred and constructed on line, that are likely to play an important role in the detection and use of analogies or similarities (Seifert, Abelson, McKoon, & Ratcliff, 1986).

It seems that research on analogy and similarity would benefit from a more realistic and finer-grained definition of the representations subjects build, which supply the very input to the analogy-detecting device. A schema-based, self-sufficient representation mode that renders recourse to analogy unnecessary (Gick & Holyoak, 1983) has all too often been opposed to a representation in the form of basic features that are not interconnected, which requires the term-to-term alignment of local properties. However, if one agrees that knowledge of a domain or of a specific case is typically represented at multiple levels of abstraction (Barsalou, 1983; Kintsch, 1988; Wisniewski & Medin, 1994), one can also contend that intermediate levels of abstraction play an essential role throughout the analogical reasoning process (Ripoll, 1998).

In proposing polymorphous modes for similarity processing, we mean that the very fruitful route explored by current models of analogy is only one among others. Most likely, the clever and adaptive nature of the human cognitive system allows for various highly contrasted ways of processing analogies. Of course, the nature of the processes involved in an analogical type of reasoning depends not only on the subject (age, intelligence level, etc.), but also on the characteristics of the experimental situation (Bassok & Medin, 1997). Accordingly, the term-to-term alignment of the local properties of analogous problems is probably necessary for highly structured stimuli that can be easily broken down into discrete units and are not conducive to the extraction of global properties likely to be used early in the comparison process. Of course, term-to-term alignment is always necessary when the task requires finding local correspondences (as in Experiments 1B and 2B) but is only optional when the task is to transfer properties from the base to the target (as in Experiments 1A and 2A). Consequently, it seems very important, from a methodological and theoretical point of view, to clearly distinguish transfer tasks and mapping tasks. On the other hand, it is likely that for semantically richer stimuli that allow for inductive or deductive inferences, subjects can take advantage of these inferences, either as guidelines for the alignment process or as support for going directly on to the analogical transfer and skipping the (complete or partial) mapping process.

This type of hypothesis is similar in a number of respects to those set forth in category-learning studies (Goldstone, 1994a; Goldstone, Lippa, & Shiffrin, 2001; Ross, 1996; Schyns, Goldstone, & Thibaut, 1998; Schyns & Rodet, 1997), where early categorizations have been found to affect feature descriptions of compared stimuli. Schyns and Rodet showed that categorization experience affects the perception of subsequent category exemplars. In other words, the context induced by the processing of a previous example may greatly influence the way a new example is encoded. In the case in which a subject is processing similarities or analogies, one can assume that the source supplies important clues about the category of the situation to be processed and, thereby, has a strong effect on encoding and on the feature-based description of the target (Ripoll

& Coulon, 2001; Sander, 2000; Zamani & Richard, 2000). This source effect on target encoding may have a substantial impact on mapping, because mapping complexity is partly determined by what source and target representations are built. In the extreme case, which probably corresponds to the experimental situation created here, the source can be seen as generating a context for target processing that permits target completion without recourse to mapping.

More generally, we believe that in theoretical approaches to analogical reasoning, the relations between representations and processing should be studied more accurately. In our opinion, actual models of reasoning by analogy have not paid sufficient attention to the issue of representation, and one cannot exclude the possibility that different assumptions about representations could lead to different assumptions about processing. By introducing the possibility that subjects extract and use global properties very early during analogical processing, we propose an alternative to the classical local-to-global approach of analogical processing (see Love et al., 1999, for the same hypothesis in the context of analogical visual processing). Nevertheless, because processing and representations are interdependent and because, in our work, we did not describe how the subjects represented the source and the target, we cannot accurately describe how representational factors constrained analogical processing. Although we are very confident that the subjects did not align local properties to complete the target, other empirical work will be necessary to accurately describe the interdependent relations that exist between representations and processing.

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APPENDIX A
Source and Target Sentences Used in Experiment 1

The cross-mapped element is shown in parentheses in the source. The words in parentheses in the target correspond to the missing part of the sentence to be filled in. The word in boldface in the target is the element to be matched.

Sentence 1

Source sentence. The mayor who dreamed of being a congressman/(chief of police) spent all his time saying that a congressman's job is totally uninteresting.

Target sentence. It is probably because that **congressman** (would have liked to be a cabinet member) that he spent all his time saying they were overpaid.

Sentence 2

Source sentence. Because he was constantly being bawled out by the general, the lieutenant took it out on the soldier/(secretary) to calm his nerves.

Target sentence. The **secretary** who was constantly being belittled (by the boss) took it out on the errand runner every chance he got.

Sentence 3

Source sentence. Even if it acts aggressively, a gorilla/(lion) will never scare an elephant.

Target sentence. A **lion** (will never be afraid of a zebra) even if it looks ready to attack.

Sentence 4

Source sentence. If an archer and a marathon runner/(cyclist) have to take an endurance test, we would expect the archer's performance to be lower.

Target sentence. A **cyclist** is expected to (do less well than a gymnast) if asked to perform a routine requiring flexibility.

Sentence 5

Source sentence. The warrior who had already conquered a region/(state) would like to conquer the whole country.

Target sentence. A commander-in-chief's aim will be to conquer a **state** if he (has already conquered a city).

Sentence 6

Source sentence. The traveller will find that Italy/(Greece) is a perfect destination if he can't pay for a trip to Australia.

Target sentence. A vacationer who doesn't have enough money to go to **Greece** (will find that Spain) is an ideal place for a vacation.

APPENDIX B
Source and Target Sentences Used in Experiment 2

The cross-mapped element is shown in parentheses in the source. The words in parentheses in the target correspond to the missing part of the sentence be filled in. The word in boldface in the target is the element to be matched.

Sentence 1

Intradomain: without and with cross-mapping source sentence. An elephant, even a small one, will always be more imposing than a gazelle/(wild boar).

Interdomain source sentence. A trap-door spider, even a small one, will always be more imposing than a termite.

Target sentence. Although quite small, (if it comes across a rabbit), a **wild boar** will feel big.

Sentence 2

Intradomain: without and with cross-mapping source sentence. The bailiff who seems so mean is in fact as gentle as a child/(teacher).

Interdomain source sentence. The grizzly bear that seems so mean is in fact as gentle as a sheep.

Target sentence. Although he seems very ferocious, this **teacher** (is as friendly as a child).

Sentence 3

Intradomain: without and with cross-mapping source sentence. Passing heedlessly by a snake that seemed harmless, the mouse/(wolf) was attacked.

Interdomain source sentence. Passing heedlessly by a pygmy that seemed peaceable, the explorer was attacked.

Target sentence. (The sheep) passing peacefully by a **wolf** that appeared to be sleeping was attacked.

Sentence 4

Intradomain: without and with cross-mapping source sentence. Envious of the success of the office worker/(the secretary), the unemployed man falsely accused him of the worst of crimes.

Interdomain source sentence. Envious of the success of the lieutenant, the soldier falsely accused him of the worst of crimes.

Target sentence. Because (he held a grudge against the director), the **secretary** started some rumors about him.

Sentence 5

Intradomain: without and with cross-mapping source sentence. Even if it acts aggressively, a Yorkshire terrier will never scare a cocker spaniel/(poodle).

Interdomain source sentence. Even if it acts aggressively, a chimpanzee will never scare a tiger.

Target sentence. (A Doberman will not be alarmed) by a **poodle** even if it looks ready to attack.

Sentence 6

Intradomain: without and with cross-mapping source sentence. A militant who would have liked to be a city councilman/(mayor) will say that it's a boring occupation.

Interdomain source sentence. The radio broadcaster who would have liked to become an opera singer will say that it's a boring occupation.

Target sentence. It is no doubt because that **mayor** had always dreamt (of becoming a congressman) that he said it was an uninteresting job.

Sentence 7

Intradomain: without and with cross-mapping source sentence. If a basketball player/(golfer) and marathon runner have to take a dexterity test, we would expect the former to get a better score than the latter.

Interdomain source sentence. If a tightrope walker and a clown have to take a dexterity test, we would expect the former to get a better score than the latter.

Target sentence. A **golfer** will probably (perform less well than a gymnast) if they both have to take a flexibility test.

Sentence 8

Intradomain: without and with cross-mapping source sentence. If it chases a pheasant and a hen at the same time, the dog/(weasel) will come back with neither.

Interdomain source sentence. If he chases a drug dealer and a thief at the same time, the policeman will come back with neither.

Target sentence. (A wolf that chases both) a hare and a **weasel** won't catch either one.

(Manuscript received March 12, 2002;
revision accepted for publication November 5, 2002.)