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Relations, Objects, and the Composition of Analogies

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Abstract

This research addresses the kinds of matching elements that determine analogical relatedness and literal similarity. Despite theoretical agreement on the importance of relational match, the empirical evidence is neither systematic nor definitive. In three studies, participants performed online evaluations of relatedness of sentence pairs that varied in either the object or relational match. Results show a consistent focus on relational matches as the main determinant of analogical acceptance. In addition, analogy does not require strict overall identity of relational concepts. Semantically overlapping but nonsynonymous relations were commonly accepted, but required more processing time. Finally, performance in a similarity rating task partly paralleled analogical acceptance; however, relatively more weight was given to object matches. Implications for psychological theories of analogy and similarity are addressed.

Keywords: Psychology; Analogy; Concepts; Human experimentation

1. Introduction

The study of analogy and similarity has made great strides over the past 2 decades. Analogical processing has been shown to play a central role in human learning and reasoning (Gentner, 2003; Hofstadter, 2001; Kokinov & French, 2002), and a large number of important phenomena have been uncovered (Gentner, Holyoak, & Kokinov, 2001; Holyoak & Thagard, 1995). In fact, researchers have achieved substantial convergence on major theoretical questions. However, there are basic issues that remain unresolved and assumptions that lack a firm empirical foundation.

Our aim in this research is to address these issues by holding a microscope to the phenomenon of analogy and to the information-processing machinery of comparison. We focus our effort on three areas of inquiry: (a) What kinds of matches underlie analogical relatedness—in particular, do relations matter more than attributes? (b) how flexible is the matching pro-

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cess—what degree of likeness between individual representational elements is required for analogy? and (c) what kind of matches underlie ordinary similarity, and do relational matches receive extra weight in literal similarity? This last question bears on whether analogy and similarity are related points on a continuum, (Gentner, 1983; Holyoak, Gentner, & Kokinov, 1995) or separate phenomena. Models of analogy need answers to these questions.

An *analogy* is a mapping between two represented situations in which common relational structure is aligned (Gentner & Markman, 1997; Holyoak et al., 2001).[1] Often, further candidate inferences are projected or common abstractions are derived, or both. People prefer an alignment that is structurally consistent: that is, one that has a one-to-one correspondence between the elements in the two domains and that satisfies parallel connectivity (meaning that the arguments of corresponding predicates must themselves correspond). The subjective evaluation of analogical goodness therefore depends heavily on the size and depth of the matching structure. In problem-solving situations, additional criteria besides the structural evaluation of size and depth typically enter into analogical acceptance: notably the factual plausibility of the projected inferences and the relevance of the analogical inferences to these goals (Gentner, 1989; Spellman & Holyoak, 1996). Although such factors are important, they will not concern us here, as we seek to address the context-general aspects of analogical processing.

Despite substantial theoretical convergence across models of analogy, there remain basic issues that are either undecided or insufficiently grounded in empirical evidence. We first briefly lay out three key issues and then review each of them in more detail.

1.1. *Open questions*

Our initial question is, What kinds of representational elements—relations, objects, or both—form the basis for a good analogical match? (Throughout this article, the term *representational elements* refers to elements at the conceptual level. That is to say, matching occurs between word meanings, not between the words themselves.)[2] According to structure-mapping theory (SMT), the evaluation of analogical relatedness depends chiefly on the size and depth of the common relational structure (the relational focus assumption; Gentner, 1983; Gentner & Markman, 1997; Markman & Gentner, 2000). Although object matches enter into the computation of a match, they have little or no effect on the evaluation of analogical relatedness. In the structure-mapping engine (SME) all matches—whether relational or attributional—enter into the process of computing an analogy or similarity comparison[3] (Falkenhainer, Forbus, & Gentner, 1986, 1989; Forbus, Gentner, & Law, 1995). SME begins by matching all identical elements between the two representations, whether relational or attributional. This rather motley set is then separated into structurally consistent clusters (called *kernels*), which are merged into the one or two largest connected mappings that still preserve structural consistency. SME uses a cascade-like algorithm in which evidence is passed down from predicates to their arguments. This algorithm favors deep, interconnected systems over shallow systems (the systematicity bias), even if they have equal numbers of matches (Forbus & Gentner, 1989). Thus, although both relations and object attributes enter into SME's alignment process, because of the systematicity bias, relational systems tend to dominate in the final selection. However, object matches are not excluded. If there are object matches consistent with the best relational match, as in literal similarity, they will be preserved in the winning match. In fact, a rich object match can dominate if the relational structure is shallow, as in some metaphors (e.g., "The road is a silvery ribbon … ").[4] But such a match will not be viewed as an analogy, but rather as a surface or mere appearance match.

Although most current accounts agree that matching relational structure is important in the perception of analogy (e.g., Keane & Bradshaw, 1988; Kokinov & Petrov, 2001; Larkey & Love, 2003; Ramscar & Yarlett, 2002), theories vary in their assumptions about the relative importance of relational matches and object matches. In Holyoak and Thagard's (1989) analogical constraint mapping engine (ACME) simulation, semantic matches of all kinds enter into judgments of analogical relatedness, with no special role for relational matches. Hummel and Holyoak's (1997, 2003) LISA model can favor either relational or object matches, depending on how its parameters are set, with the default weighting favoring relational matches (J. E. Hummel, personal communication, March 2004). Keane, Hackett, and Davenport (2001) emphasized the role of object matches in analogical processing and have suggested that object matches may be on a par with relational matches in analogical matching, contrary to the relational dominance assumed in structure mapping. We return to the comparison of analogical models in the General discussion. For now, our first goal is to clarify how object matches and relations matches act to determine analogical relatedness.

The second question concerns flexibility in the comparison process. It seems intuitively clear that an analogical match can be supported by nonsynonymous relations, provided they are sufficiently conceptually similar. For example, "Fred *purchased* a firecracker" can presumably be matched not only with a statement having a synonymous relation (such as "Fred *bought* a firecracker"), but also with a nonsynonymous, partially overlapping relation such as "Fred *obtained* a firecracker." The evidence on such flexibility is largely impressionistic. Therefore, a goal of this research is to test directly whether nonsynonymous relations are accepted in analogical matches. We also ask the further question of *how* such matches occur. In particular, is some kind of online process of adjustment or rerepresentation required to arrive at nonsynonymous matches? In this research we seek an empirical evaluation of analogical matching that will yield appropriate constraints on process models. Under what conditions and by what means can elements that differ in meaning count as analogy-supporting matches? Computational models have used a number of methods to model this adjustment process as amplified later.

The third question deals with the relation between analogy and ordinary literal similarity. In structure mapping, similarity and analogy are closely related in that both are computed by the same alignment process (Forbus et al., 1995). Once the maximal mapping is determined, it will be considered an analogy if it contains only matching relational structure, and a *literal similarity* match if it contains both relational structure and common attributes. This follows from Gentner's (1983, 1989) theoretical formulation in which an analogy requires common object relational structure, a mere appearance match derives from common objects or object attributes, or both, and a literal similarity match requires both. This formulation predicts considerable overlap in the psychology of analogy and literal similarity, a prediction we test in Experiment 3.

We now review existing evidence on the three issues. We begin with the interrelated issues of relational focus in analogy and the relation between similarity and analogy. Then we turn to flexibility.

1.2. Relational focus in analogy

There are several sources of support for the claim that the evaluation of analogical judgments depends chiefly on relational matches. One line of evidence comes from ratings of the aptness of metaphors that behave in many ways like analogies (Gentner, Bowdle, Wolff, & Boronat, 2001). Gentner and Clement (1988) compared people's object descriptions with their interpretations of metaphors that contained these objects. Whereas the object descriptions contained both object attributes and relations, the metaphor interpretations contained mostly relational information. A number of studies have shown that people consider metaphors that convey relational matches more apt than those that convey attributional matches (Gentner, 1988; Gentner & Clement, 1988; Zharikov & Gentner, 2002). Aisenman (1999) found evidence that people use the metaphor form—thought to be the stronger form—for pairs that share common relations and the weaker simile form for pairs that share common attributes. In addition, Gentner and Clement found a positive correlation between people's ratings of the aptness of metaphors and the (independently scored) relationality of their interpretations, as well as a negative correlation between metaphorical aptness and attributionality.

Another source of evidence as to which kinds of matches are important in analogical processing comes from assessing the effects of analogical comparison on transfer to novel materials. In their classic studies, Gick and Holyoak (1983) showed that participants who compare two analogous stories are more likely to transfer the common relational structure to solve a further analogous problem than are those who see only one story. Subsequent research has further shown that comparing two cases potentiates relational transfer compared to seeing the same two cases separately (Catrambone & Holyoak, 1989; Gentner, Loewenstein, & Thompson, 2003; Loewenstein, Thompson, & Gentner, 1999). This suggests that comparing two things makes their common relational structure more salient and is consistent with the claim of relational focus during analogical processing.

A limitation of these studies is that the analogous pair shared only relational structure. Thus, the evidence is consistent with either the possibility that comparison highlights common relations or with the simpler possibility that comparison highlights any commonalities (and the pairs used in the studies just happen to have had purely relational commonalities).[5] The question is whether relational structure is preferentially highlighted when both kinds of commonalities are present. The answer appears to be yes. Recent studies have found evidence for relational highlighting even for pairs that share both objects and relations (Gentner & Namy, 1999; Jameson & Gentner, 2003; Loewenstein & Gentner, 2001; Namy & Gentner, 2002).

One method that pits common relations against common objects is Gentner and Toupin's (1986) cross-mapping technique, which uses pairs in which the obvious object matches are inconsistent with the correspondences required for the maximal relational match (see also, Ross, 1987). Markman and Gentner (1993) used a *one-shot mapping task* to assess which correspondences people choose when confronted with *cross-mapped* pairs. People saw pairs of pictures such as *a man repairing a robot* and *a robot repairing a car* and were asked to say which object in the second scene went with the cross-mapped object (the robot) in the first scene. The object matches were designed to be highly salient; and indeed, participants chose the object match about 65% of the time. However, if participants were first asked to rate the similarity of the scenes, they were significantly more likely to choose the relational match. (Object matches dropped to 30%, with 70% relational matches.) Markman and Gentner (1993) concluded that the comparison process induced a structural alignment whereby the common relational structure became more salient.

The most thorough-going investigation of how people judge analogical relatedness across different kinds of matches is the "Karla the Hawk" series conducted by Gentner, Rattermann, and Forbus (1993). They gave people pairs of stories that varied systematically in the nature of their overlap: either common relational structure or common objects and entities, or both or neither. Participants were asked to rate inferential soundness—that is, whether one story could be used to draw inferences about the other (an operationalization of analogical relatedness). Pairs that shared deep relational structure were rated as substantially more sound than those that did not; there was no contribution of object similarity to the soundness ratings. Gentner et al. (1993) concluded that analogical relatedness depends chiefly on the degree to which pairs share relational structure.

In evaluating the generality of these results, we note two limiting factors. The first is that the stories were characterized by fairly deep causal structures linking a fairly small number of entities. Not only did the relational matches outnumber the object matches, but, in addition, the relational matches included higher order connecting relations such as *cause* and *prevent,* which served to link other relations into deep relational structures. The preference for relational matches is thus in accord with Gentner's (1983, 1989) *systematicity* principle that deep nesting confers greater weight to the component relations (Forbus & Gentner, 1989). However, it remains an open question whether relations are more important than object matches in analogical evaluation when the number of matches is equated. The second limitation is that we assessed by ratings of analogical relatedness as rated inferential soundness. This evaluation may be driven by factors about task interpretation, as well as the content of the stories themselves, rather than being based strictly on the relation that holds between stories. Accordingly, one goal of this research was to fill the need for a direct evaluation of relational focus using numerically equated matches and explicit judgments of analogical relatedness.

1.3. Similarity and analogy

Literal similarity, by definition, involves an overall match at all levels. However, there is considerable support for the claim that "similarity is like analogy." According to this view, matches in relational structure are weighed more heavily than object attribute matches, even in literal similarity judgments (Gentner & Markman, 1995; Goldstone, 1995; Markman & Gentner, 2000; Medin, Goldstone, & Gentner, 1993). One line of evidence that supports the claim that carrying out a similarity comparison highlights relational structure comes from the one-shot mapping task (described previously) used to assess which correspondences people choose when confronted with pairs with competing relational and object matches (Markman & Gentner, 1993). Prior generation of a simple similarity rating led participants to show a strong preference for the relational match relative to a control group.

However, object matches clearly also mattered in this task. Participants in the control group, who performed the one-shot mapping task without a prior similarity judgment, chose the object match more than half the time. Even after a similarity comparison, despite higher levels of relational responding, the object match was chosen about 30% of the time. Another study that shows effects of object matches in the one-shot mapping task is that of Keane et al. (2001). They found set effects in the likelihood of object versus relational matches in alignment; they found that people's propensity to choose object or relational matches could be influenced by providing several trials in which this match type was highly salient. In general, studies have shown that object matches increase with the richness and distinctiveness of the local object matches, whereas relational matches are more likely the deeper the matching relational structure (Gentner & Rattermann, 1991; Loewenstein & Gentner, 2001, 2005; Markman & Gentner, 1993; Paik & Mix, 2005).

Another source of evidence on the similarity process comes from research using a transfer paradigm to evaluate what is retained after a similarity comparison is made. As discussed previously, when people are led to compare purely analogous pairs, they subsequently show better relational transfer than when given the same materials without comparison. Of course, by the nature of analogy, the only possible commonalities that can be discovered in such pairs are relational commonalities. However, several recent studies have suggested that relational focus is a general outcome of the comparison process. These studies have investigated people's transfer after comparing pairs that shared both objects and relations—that is, literal similarity pairs (Gentner & Namy, 1999; Jameson & Gentner, 2003; Kotovsky & Gentner, 1996; Loewenstein & Gentner, 2001; Namy & Gentner, 2002). In this research, both adults and young children have shown elevated relational focus after making a literal similarity comparison.

Finally, a direct inquiry as to which kinds of matches contribute most to similarity was also conducted as part of the Karla the Hawk series. Gentner et al. (1993) had participants rate the similarity of pairs of stories whose matches formed a 2×2 design: objects (matching or not) and higher order relational structure (matching or not). As with the soundness ratings described previously, pairs that shared relational structure were rated as substantially more similar than those that did not. However, in contrast to the soundness ratings, there was a small but significant contribution of object similarity to the similarity ratings. Gentner et al. (1993) concluded that similarity, like analogy, depends heavily on the degree of common relational structure but that object matches also contribute to ordinary similarity.

These findings are consistent with the claim that similarity involves commonalities between both relations and objects. However, as noted previously, the Karla the hawk stories described rich causal scenarios over a small number of participants. Although this kind of structure is typical in both narrative and explanatory texts; it introduces an imbalance: The common relations outnumber the common objects. In these studies, we aimed to create a more level playing field by testing whether a single relational match would dominate over a single object match.

1.4. Flexibility

To capture human analogical judgments, it is necessary to incorporate a degree of flexibility in the relational match process (Dietrich, 2000; Gentner, Rattermann, Markman, & Kotovsky, 1995; Gentner & Wolff, 2000; Hofstadter, 1995; Hummel & Holyoak, 1997; Keane, 1996; Kurtz, Miao, & Gentner, 2001; Yan, Forbus, & Gentner, 2003). There are many intuitive examples of analogies that involve correspondences between different relations. For example, people readily perceive the relational commonality between the following two statements:

(1) John **bought** the pamphlet.
(2) Alex **took** the pamphlet.

Although these actions are not the same, they share a common conceptual relation: obtaining a pamphlet. Accounts of analogy certainly ought to accommodate this degree of flexibility, but it is crucial to stop short of indiscriminate matching that leads to the acceptance of bizarre or unacceptable matches such as

(1) John **bought** the pamphlet.
(3) Alex **folded** the pamphlet.

Direct empirical tests of analogical flexibility are somewhat scanty; indeed, that is one motivation for this research. However, there is some indirect evidence for this kind of flexibility. In the Karla the Hawk studies, first-order relational matches were highly similar, but not perfectly synonymous relations, as in the following example sentences: People readily viewed cases such as (2) as analogous to the base (1)

(1) … the mockingbird *visited* a squirrel and *sang* a song for her, *expecting to get* some of the squirrel's sunflower seeds *in return.*
(2) … the magpie *paid a visit* to a chipmunk and *performed a ballad* for her, *hoping* she would *give* him some nuts *in return.*

Even more distant matches have been documented. In Gick and Holyoak's (1983) studies, it can be inferred that participants achieved correspondences between

(1) "If many buckets of water were thrown at once, a large volume of water would hit the fire at the same time, so it would be extinguished" and
(2) "If all the groups of soldiers moving on different roads arrived at the fort together, they would capture the fortress."

Analogy theorists have proposed a number of computational approaches to semantic flexibility. One possibility is a precomputed similarity table (Holyoak & Thagard, 1989) in which, for example, the known similarity of *bought* and *took* (to return to our earlier example) is high enough to justify a match, whereas that of *bought* and *folded* is not. This method has a number of drawbacks. It is inflexible and makes implausible storage demands. Worse, it is inherently unable to capture a large class of metaphorical mappings that rely on contextually variable dimensional correspondences such as *down* → *sad* or *down* → *bad* (e.g., Lakoff & Johnson, 1980). For example, a statement such as "Been down so long it feels like up to me" requires the *up/down* → *happy/sad* mapping; but a line such as "The party in power has sunk to new depths of corruption and dishonesty" requires the *up/down* → *moral/immoral* mapping. Also, a similarity table fails to match a significant aspect of the human pattern in that it does not reveal which aspects of the two relations match, but merely whether they can be matched. This means it cannot adequately capture the findings reviewed previously showing that comparison leads to the extraction and highlighting of common relational structure.

SME (Falkenhainer et al., 1989) requires synonymous (that is, conceptually identical) relations to achieve an analogical mapping,[6] in accord with the theoretical view that comparison is driven by evaluating cases for common relational structure. However, SMT and its implementation, SME, do not require initial identicality—relations can be rerepresented to achieve partial identity (explanation to follow). To achieve flexibility, the approach in SME is to rerepresent nonidentical conceptual relations as partial identity matches (*tiered identicality*). Yan et al. (2003) proposed criteria for when such rerepresentation should occur: for example, when the two nonmatching predicates are part of larger structures that have other matches, making the potential match valuable.

As to how rerepresentation occurs, there are two general approaches in computational models for finding the commonality of constituent elements (Forbus et al., 1995; Yan et al., 2003). One method for achieving identicality uses relations to other concepts in a network. For example, Thagard, Holyoak, Nelson, and Gochfeld (1990) used superordinate and other semantic connections from WordNet (Fellbaum, 1998) to find matches. Falkenhainer's (1990) PHINEAS system, which constructed physical explanations by analogizing over previous examples, used a form of rerepresentation called *minimal ascension.* In this method, the relations *buy* and *take* (for example) would be identified as subclasses of a common superordinate such as *obtain.* PHINEAS did not automatically rerepresent any two nonmatching predicates (To do so would lead to analogical hallucinations.) Rather, it attempted representation when the two nonmatching predicates were causal antecedents of a matching predicate.

The second approach for rerepresenting similar but nonidentical relations is *semantic decomposition*—breaking down predicate representations into the structured systems of subcomponents that encode the meaning of the relational term (e.g., Fillmore, 1971; McCawley, 1968). Such decompositions are then compared to reveal identity matches among the components (Gentner, 1983; Yan et al., 2003). As an example, the following two relational predicates can be rerepresented in terms of a common underlying semantic element:

BUY (pamphlet) $\rightarrow$ CAUSE (PAY FOR (pamphlet), OBTAIN (pamphlet))
GRASP (pamphlet) $\rightarrow$ CAUSE (PICK UP (pamphlet), OBTAIN (pamphlet))

In this example of decomposition, an identical semantic element (obtaining the pamphlet) is found within the meanings of both predicates. Both rerepresentation methods have been implemented as functionalities available to SME to translate semantically differing relations into partial identities during the mapping stage of analogy (Yan et al., 2003).

Another version of semantic decomposition is found in Hummel and Holyoak's (1997, 2003) learning and inference with schemas and analogies (LISA) model in which symbolic assertions are represented as distributed feature representations, including representations of the argument roles. Conceptually similar, but nonidentical, predicates will have matches on some but not all of these features. This approach differs from SME's in that in LISA the distributed feature representation is activated immediately during the mapping process, rather than being invoked selectively when rerepresentation is triggered. In contrast to SME's mechanism of comparison-driven decomposition (or minimal ascension), LISA automatically begins the mapping with microfeature representations of each case entering into comparison. Flexibility is achieved through partial matching over these microfeature representations. An important difference between these approaches[7] is that LISA's mapping process always involves a semantic decomposition. Specifically, even the simplest mapping requires that a featural representation of the meaning of each term be instantiated in the computational work space. One critical consequence of such automatic decomposition is that a comparison requiring rerepresentation should require no additional processing time over a synonymous match.

1.5. Overview of experimental approach

Experiments 1 and 2 were conducted to address the first two questions laid out previously: (a) What kinds of matches form the basis for analogical relatedness? and (b) how flexible is the matching of representational elements? We take up the question of literal similarity in Experiment 3. In the first two studies we assessed the analogical acceptance rate for sentence pairs that varied in their degree of relational and object match. In constructing the materials, we were guided by three considerations. First, we needed to ensure a "level playing field" for relations and objects; that is, to avoid the problem of having a large number of relations over a small set of objects (as in prior studies). Second, the materials had to have clearly delineated relational and object components. Third, we needed to be able to vary the degree of relational match and the degree of object match independently through at least three levels of match closeness. To achieve these ends, we used simple transitive sentences such as "John bought the candy" and created sentence pairs (see Tables 1 and 2) by varying either the verb (and thus the relational match) or the object noun (and thus the object match). The subject nouns were always proper nouns matching in gender as exemplified in Table 1. On each trial, a participant viewed a pair of sentences and gave a timed response as to whether the pair was or was not analogically related. There were three levels of relational match and three levels of object match, both manipulated within-subjects.

These materials allow us to compare the effects of varying the degree of object match with those of varying the degree of relational match. If, as in structure mapping, relational matches are more crucial to analogical relatedness than object matches, then there should be a strong effect of relational similarity, but not object similarity, on the analogical judgments. That is, a relationally close pair such as *John bought the candy–Mike purchased the candy* should be considered a stronger match than a less relationally similar pair such as *John bought the candy–Mike took the candy.* However, a decrease in object similarity should have little or no in-

Table 1
Experimental design and predictions (sample standard sentence: John bought the candy.)

Condition	Target Sentence	Predicted Response	Predicted Latency
Verb change			
Synonym	Mike **purchased** the candy.	Yes	Fast
Near	Mike **took** the candy.	Yes/No	Slow
Far	Mike **stepped** on the candy.	No	Fast
Noun change			
Synonym	Mike bought the **sweets**.	Yes	Fast
Near	Mike bought the **sandwich**.	Yes	Fast
Far	Mike bought the **bookshelf**.	Yes	Fast

Table 2
Examples of experimental materials

Standard	Verb-Change	Noun-Change
Alan watched the parade.		
Syn	Brian observed the parade.	Brian watched the procession.
Near	Brian heard the parade.	Brian watched the demonstration.
Far	Brian planned the parade.	Brian watched the airplane.
Rich ran to the store.		
Syn	Bill jogged to the store.	Bill ran to the mall.
Near	Bill drove to the store.	Bill ran to the school.
Far	Bill opened up the store.	Bill ran to the creek.
Fred reclined on the couch.		
Syn	Carl lay on the couch.	Carl reclined on the sofa.
Near	Carl sat on the couch.	Carl reclined on the bed.
Far	Carl sneezed on the couch.	Carl reclined on the grass.
Dan swallowed the orange juice.		
Syn	Jay drank the orange juice.	Jay swallowed the lemonade.
Near	Jay slurped the orange juice.	Jay swallowed the ice water.
Far	Jay made the orange juice.	Jay swallowed the pill.
Don honored the soldier.		
Syn	Joe decorated the soldier.	Joe honored the warrior.
Near	Joe thanked the soldier.	Joe honored the sailor.
Far	Joe warned the soldier.	Joe honored the agreement.
Greg built the deck.		
Syn	Chad constructed the deck.	Chad built the porch.
Near	Chad repaired the deck.	Chad built the woodshed.
Far	Chad swept the deck.	Chad built the sand castle.
Jake drove the car.		
Syn	Phil operated the car.	Phil drove the van.
Near	Phil turned the car.	Phil drove the snowmobile.
Far	Phil bought the car.	Phil drove the lawn mower.
Sarah stared at the plane.		
Syn	Kathy gazed at the plane.	Kathy stared at the helicopter.
Near	Kathy glanced at the plane.	Kathy stared at the kite.
Far	Kathy cursed at the plane.	Kathy stared at the dancer.
Beth remained in the classroom.		
Syn	Jill stayed in the classroom.	Jill remained in the school.
Near	Jill lounged in the classroom.	Jill remained in the church.
Far	Jill shouted in the classroom.	Jill remained in the line.
Mary tethered the boat.		
Syn	Julie tied the boat.	Julie tethered the ship.
Near	Julie anchored the boat.	Julie tethered the Jet Ski.
Far	Julie sank the boat.	Julie tethered the horse.
Cindy inspected the house.		
Syn	Linda scrutinized the house.	Linda inspected the home.
Near	Linda surveyed the house.	Linda inspected the restaurant.
Far	Linda departed the house.	Linda inspected the files.
Alice studied the butterfly.		
Syn	Debby examined the butterfly.	Debby studied the moth.
Near	Debby noticed the butterfly.	Debby studied the spider.
Far	Debby frightened the butterfly.	Debby studied the storefront.

Table 2 *(Continued)*

Standard	Verb-Change	Noun-Change
Susan questioned the butler.		
Syn	Laura interrogated the butler.	Laura questioned the doorman.
Near	Laura reprimanded the butler.	Laura questioned the driver.
Far	Laura hired the butler.	Laura questioned the passerby.
Ashley abandoned the dog.		
Syn	Megan deserted the dog.	Megan abandoned the puppy.
Near	Megan mistreated the dog.	Megan abandoned the bird.
Far	Megan approached the dog.	Megan abandoned the house.

fluence on judgments of analogical relatedness. There should be little or no difference in analogical acceptance between *John bought the candy–Mike bought the sweets* (high object similarity) and *John bought the candy–Mike bought the sandwich* (intermediate object similarity).

These materials also allow us to test match flexibility. If perfect relational synonymy is required for analogy, then the results will be dichotomous: synonymous relational matches will be accepted, and the two nonsynonymous classes will be rejected. However, if partial relational matches can also be accepted, then we will see a gradient in acceptance rate from relationally synonymous pairs (e.g., *bought* and *purchased*) to pairs with moderate relational similarity (e.g., *bought* and *took*) to those with little or no relational similarity (e.g., *bought* and *stepped on*). No such predictions are made for object similarity—which is predicted to be largely irrelevant to analogical acceptance. By measuring response time (RT) we can also test issues concerning the *process* by which analogies are computed. If a rerepresentation process such as the one employed by SME holds for similar but nonsynonymous relations, then pairs with moderate levels of relational similarity will take longer to process than pairs with synonymous relations.

2. Experiment 1

We collected judgments of analogical relatedness between pairs of sentences. The sentences were designed to be simple and clearly interpretable: for example, "John bought the candy." For each standard sentence, we constructed six possible sentence pairs—each based on changing either the noun or the verb of the standard sentence. In each case, we tested three levels of similarity between the original keyword and the substitution. In sum, match type and match similarity were manipulated in a 2 × 3 factorial design as within-subjects variables. Thus we could test match focus by varying either relational similarity (across the three kinds of verb match) or object similarity (across the three levels of object–noun match).

The predictions derived from SMT are as follows. First, because relational matches will dominate in analogical evaluation, noun-change pairs (sharing the same verb) will be judged analogous at a higher rate than verb-change pairs (sharing the same noun). Second, the likelihood of analogical acceptance should vary with the degree of verb similarity, but not with the degree of noun similarity. A further set of predictions concerns how people arrive at the analogical alignment. If there is flexibility in relational matching—so that similar, but nonidentical, predicates can be aligned—then near-verb pairs will be accepted at a higher rate than far-verb pairs. Further, if, as in SME, some kind of additional rerepresentation processing is required to align predicates that have only partial semantic overlap, then near-verb pairs should take longer to process than synonymous (syn-verb) pairs. Table 1 provides a summary of the design and expected pattern of results.

2.1. Method

2.1.1. Participants

Twenty-two undergraduate students from Northwestern University participated for course credit.

2.1.2. Design and materials

The design was a 2 × 3 factorial of match type (noun change or verb change) and similarity (syn, near, or far), both within-subjects variables. Forty-two stimulus sets were constructed based on a standard sentence and six variations. As demonstrated in Table 1, three levels of variation were applied using a synonym (syn), a semantically close word (near), or a semantically distant word (far). Table 2 shows a representative group of 12 stimulus sets, including the six variations of each standard sentence. It should be noted that the syn pairs were often not perfectly identical in meaning, but as close as possible. The near pairs were designed to have a considerable degree of semantic overlap, yet remain clearly distinct in meaning. The far pairs were designed to avoid any obvious overlap in meaning. Each keyword appeared once across the entire item set. Nearly every variation replaced the keyword with a single substituted word; however there were a few items (such as "stepped on" in the example from Table 1) in which a verb plus particle was used.

To forestall possible response biases, a set of 21 filler pairs was randomly dispersed through the task. These items featured both a semantically distant verb and a semantically distant noun and were intended to be nonanalogous. The purpose of including these items was in part to more evenly balance the expected rates of acceptance versus rejection on the analogical judgment task. Another purpose was to forestall participants' noticing the structure of the manipulation. Because some pairs varied by only one word, whereas others varied by two words, participants could not assume that if they located a mismatch on either the verb or noun, the other would be a match. Each pair used a different pair of high-familiarity first names as the subject of each sentence. The use of a different sentence subject (person) for each sentence served to discourage an interpretation of the two sentences as a sparse episodic description of two serially connected events. Male and female names were both used, but gender was held constant within each pair.

2.1.3. Procedure

Participants were asked to judge whether the pairs of sentences were analogous and to respond as quickly as possible without sacrificing accuracy. Instructions were given that explained *analogy* as "cases where the same idea is expressed across two situations that may or may not be alike on the surface." Three examples were provided: an analogy with differing verbs and objects, a nonanalogy with differing verbs and objects, and an analogy with the same verb (to underscore that literal similarity in the form of lexical identity counts as analogy due to the "shared basic idea").

After three practice trials, participants carried out the 63 trials (42 test pairs and 21 filler pairs) of the study. The assignment of the 42 item sets to conditions was randomized by participant, but constrained so that each item type occurred an equal number of times for each participant (seven). Item presentation order (including the filler items) was randomly determined for each participant. On each trial, a fixation point appeared followed by presentation of only the target sentence (one of the six possible keyword variations from the base). After an interval of 3.5 sec, another fixation point appeared at a point lower on the computer screen, immediately followed by the standard sentence and the prompt to make a judgment as to whether the two sentences were analogous. The first sentence remained visible throughout the trial. Participants responded by pressing one of two keys labeled *Yes* and *No,* located on opposite sides of the keyboard. The presentation of the standard sentence always followed the variable sentence, so that all participants received the same stimulus as the cue for their timed response. This ensured that reaction time always measured the time to respond to the same stimulus regardless of item condition.

2.2. *Results and discussion*

The results (see Table 3) are consistent with the predictions of SMT. As predicted by relational focus, judgments of analogical relatedness were highly sensitive to the degree of rela-

Table 3
Proportion of analogical acceptance and acceptance latencies in Experiments 1 and 2

	Verb		Noun	
	M	*SD*	*M*	*SD*
Analogical Acceptance				
Experiment 1				
Syn	.95	.08	.94	.14
Near	.57	.28	.92	.18
Far	.18	.28	.75	.28
Experiment 2				
Syn	.96	.07	.98	.06
Near	.60	.22	.97	.09
Far	.14	.22	.86	.21
Acceptance Latency (msec)				
Experiment 1				
Syn	1,470	424	1,400	296
Near	1,962	299	1,460	226
Far	2,210[a]	762[a]	1,834	654
Experiment 2				
Syn	1,633	577	1,559	411
Near	2,158	911	1,646	439
Far	2,317[a]	1,127[a]	1,701	471

[a]Denotes very few responses.

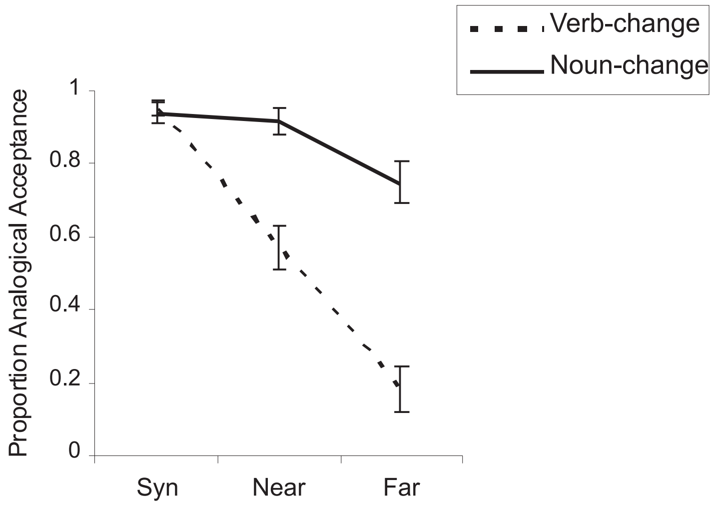

Fig. 1. Mean analogical acceptance rates in Experiment 1.

tional match and much less sensitive to the degree of object match. The rate of analogical acceptance dropped steeply as the semantic similarity of the verbs decreased (see Fig. 1). By contrast, the noun-change items showed comparatively little drop-off in rate of acceptance with decreasing similarity (recall that the noun-change items all have identical verbs). In addition to bearing out relational focus, these results accord with the predictions of match flexibility. The drop in analogical acceptance with decreasing relational similarity was not a step function; rather, the rate of acceptance varied continuously with the similarity of the verbs. Finally, the results are consistent with activation of a rerepresentation mechanism for moderate similarity relations. The accepted near-verb items showed an elevation in RT of approximately 0.5 sec compared to the accepted syn-verb items.

2.2.1. Analogical acceptance

A two-way analysis of variance (ANOVA) of the mean rates of analogical acceptance was conducted to evaluate the role of match type and degree of semantic similarity. As predicted, there was a main effect of match type. Noun-change items (with same verb) were more likely to be accepted than verb-change items (with same noun), $F(1, 20) = 73.34$, mean square error [MSE] = .041, $p < .001$. In addition, the degree of analogical acceptance differed reliably, depending on semantic similarity such that closer examples were more frequently considered analogous, $F(2, 20) = 38.79$, $MSE = .045$, $p < .001$. The key prediction concerns the interaction between the two factors. We expected to see degree of semantic similarity play a greater role for verb-change items than for noun-change items. Indeed, the interaction between match type and degree of semantic similarity was significant, $F(2, 20) = 31.13$, $MSE = .027$, $p < .001$. This supports the relational focus prediction that semantic similarity affects analogical relatedness differently depending on match type: Relations matter more than objects.

The filler items were judged to be nonanalogous by participants, as intended in the experimental design. The proportion of acceptances for these items was uniformly low (M = .05). This manipulation check suggests that participants were attentive to the materials.

To pinpoint the source of the observed main effects and interaction, we performed a set of planned comparisons. The pairwise comparisons of primary interest were between the neighboring levels of semantic similarity (syn vs. near and near vs. far) for verb-change and noun-change items, as well as between the two match types (verb change vs. noun change) at each level of semantic similarity. A significant difference was observed between syn verb (M = .95) and near verb (M = .57), $t(21) = 6.09$, $p < .001$, but not between syn noun (M = .94) and near noun (M = .92), $t(21) = .92$, $p > .3$. Near-verb items were accepted more than far-verb items (M = .18), $t(21) = 7.39$, $p < .001$. At this extreme, noun similarity also mattered: Near-noun items were more likely to be accepted than far-noun items (M =.75), $t(21) = 2.76$, $p < .05$. An ancillary analysis using a Bonferroni correction for multiple tests reaffirms each of the pairwise differences except the last one: Under the more conservative test, far-noun items are not reliably less accepted than near-noun items. The steeper gradient of acceptability for verbs than for nouns bears out the key prediction of relational focus. However, the initial claim that only the relational matches matter must be modified to state that relational matches matter much more than object matches. In addition, the fact that analogical acceptance declines steadily with relational similarity (rather than showing an all-or-nothing drop) is consistent with the claim of flexible matching; it suggests that verbs that overlap partially can be reconstrued to make a better match.

From the perspective of match type, near-noun items were significantly more likely to be accepted as analogies than near-verb items, $t(21) = 5.68$, $p < .001$, and far-noun items were significantly more likely to be accepted than far-verb items, $t(21) = 9.16$, $p < .001$. Again, recall that the noun-change items all have identical verbs, and the verb-change items, identical nouns; thus, these results indicate that pairs with matching verbs are more likely to be accepted than those with matching nouns. The syn-verb and syn-noun items showed no difference, $t(21) = .21$, $p > .8$; as expected, these items were nearly always accepted. This set of tests gives strong statistical support to the qualitative pattern seen in the means. These results bear out the claim that relational matching is crucial to a sense of analogical relatedness. When the verbs were very different, over 80% of the participants rejected the match despite having identical nouns. However, the modest decline in analogical acceptance for far-noun items suggests object matches may also contribute to a much lesser degree. We conclude that the evaluation of analogical relatedness depends chiefly on the degree of semantic similarity of the relational match.

2.2.2. *Response latency for acceptances*

Reaction times are reported as means in milliseconds of positive responses (analogical acceptances). The raw data were checked for outlier RTs that would indicate a lapse of concentration by the participant, but none were found. This is not surprising because the total duration of the task was fairly short (on the order of 15 min), and the instructions emphasized the importance of alertness during the task. We found support in a planned comparison for the prediction that it would take longer to process near-verb pairs as analogies than syn-verb pairs, $t(21) = 4.07$, $p = .001$. This pattern was not found for nouns: near-noun and syn-noun pairs took approximately the same amount of time to accept as analogous, with no evidence of a statistically reliable difference, $t(21) = .28, p > .7$. We conclude that matches between similar, but distinctly different, relations require additional time to accept. Object matches of the same character have no such impact on processing time. The fact that this RT difference is specific to verbs underscores the importance of finding a relational match in analogical alignment. Further, the pattern across levels of verb similarity is consistent with the possibility that a rerepresentational process is occurring for the near-verb pairs—for example, a decomposition of the relations into underlying semantic components such that an identical match can be found among the subrelations of the verbs's meanings.

3. Experiment 2

Experiment 2 served two goals. First, given the novel paradigm and stimulus materials, we wanted to replicate Experiment 1 with a larger group of participants and minor improvements to the procedure and materials (changes to the synonymous, near, or far keyword were made in 6 of the 42 item sets). Second, we wanted to probe further into the processes underlying analogical mapping—specifically, into whether finding relational identities is crucial to analogy. Therefore, we first gave people the same analogical acceptance task as in Experiment 1. Then, after having completed the task, participants were given a subset of the pairs and asked to again give their assessment of their analogical acceptability plus a justification for each response. We asked for justifications after the fact rather than online, because to do so online would have interfered with collecting RTs and because of evidence that similarity judgments can be altered when participants give their justifications immediately after each judgment (Bassok & Medin, 1997). Our assumption was that in most cases what would come to mind most easily would be the commonalities made salient in the just-prior online analogical evaluation task. Thus, although not perfect, these justifications can serve as a source of insight into analogical processing. Our main prediction is straightforward: When asked to explain why verb-change items are analogous, especially for the near-verb items, we expect participants to mention an underlying semantic commonality. Such a finding would again demonstrate the importance of common relations. In addition, it would be evidence for rerepresentation processes that find partial relational identities that permit the alignment of nonidentical relational predicates.

3.1. Method

3.1.1. Participants

Forty-eight undergraduate students from Northwestern University participated for course credit.

3.1.2. Design and materials

As in Experiment 1, the design was a 2 × 3 factorial of match type (noun change or verb change) and similarity (syn, near, or far). The item sets from Experiment 1 were used. As a methodological improvement, the random assignment of the 42 sentence sets to item conditions for each participant was replaced by counterbalanced item assignment. The six possible item types for each item (three levels of verb change and three levels of noun change) were each randomly assigned to one of the six item sets. The assignment of participants to item sets was counterbalanced such that each participant saw only one pair from a given sentence set.

3.1.3. Procedure

The procedure was the same as that used in Experiment 1 except that (a) participants were randomly assigned to one of the six counterbalancing conditions; and (b) after completion of the analogical acceptance task for all items, an additional justification task was conducted on a subset of the stimulus materials (the 12 sentence sets shown in Table 2). On each justification trial, participants were shown a sentence pair and asked to make an untimed analogical acceptance judgment along with a written justification of their response. The sentence pairs were presented together on paper rather than in sequence on the computer screen as in the initial judgments.

3.2. Results and discussion

The main goals of this experiment were to test whether the results of Experiment 1 would replicate and to seek additional evidence to differentiate among possible explanations for the pattern of results—particularly with respect to rerepresentation. The first goal was met as the results of E2 closely paralleled those of E1 (see Table 3). As before, the qualitative effect of decreasing similarity was strikingly greater for verb-change items (M = .96, .60, and .14 for syn-, near-, and far-verb items, respectively) than for noun-change items (M = .98, .97, .86, respectively). Mean performance on two specific item sets is shown in Table 4.

A two-way ANOVA was conducted to evaluate the role of match type and semantic similarity in analogical acceptance. The data for one stimulus item on one of the six forms was removed due to a programming error in which the incorrect sentence was displayed. Main effects were observed for both factors: match type, $F(1, 45) = 342.22$, $MSE = .028$, $p < .001$), and semantic similarity, $F(2, 45) = 226.77$, $MSE = .046$, $p < .001$. As predicted, the interaction between the two factors was significant, $F(2, 45) = 195.36$, $MSE = .018$, $p < .001$. Planned comparisons of primary interest were carried out as in Experiment 1. A significant difference was

Table 4
Proportion of analogical acceptance for two sample items in Experiment 2

	Verb-Change		Noun-Change	
Standard	Sentence	*M*	Sentence	*M*
Greg built the deck.				
Syn	Chad constructed the deck.	1.00	Chad built the porch.	1.00
Near	Chad repaired the deck.	.63	Chad built the woodshed.	1.00
Far	Chad swept the deck.	.00	Chad built the sand castle.	.75
Rich ran to the store.				
Syn	Bill jogged to the store.	.88	Bill ran to the mall.	1.00
Near	Bill drove to the store.	.75	Bill ran to the school.	.88
Far	Bill opened up the store.	.00	Bill ran to the creek.	1.00

observed between syn verb ($M = .96$) and near verb ($M = .60$), $t(46) = 11.14$, $p < .001$, and between near-verb items and far verb ($M = .14$), $t(46) = 12.56$, $p < .001$. For nouns, as in Experiment 1, a decline in acceptance occurred only for the most extreme level of dissimilarity. Levels of acceptance did not differ between syn noun ($M = .98$) and near noun ($M = .97$), $t(46) = .69$, $p > .4$, but did differ between near noun and far noun ($M = .86$), $t(46) = 3.52$, $p < .01$. From the perspective of match type, the same pattern was once again observed. Near-noun items were significantly more likely to be accepted as analogies than near-verb items, $t(46) = 10.03$, $p < .001$, and far-noun items were significantly more likely to be accepted than far-verb items, $t(46) = 18.35$, $p < .001$. The syn-verb and syn-noun items, both with near-perfect acceptance, did not differ from each other, $t(46) = 1.14$, $p > .25$.

For the latency measure, we set a maximum response latency of 7,000 msec, four times longer than the average RT in Experiment 1. A total of nine measurements were removed as outliers. In addition, 1 participant was removed for consistently failing to respond before the cutoff time. We again found support for the prediction that near-verb items would take longer to accept than syn-verb items, $t(45) = 3.95$, $p < .001$, consistent with the claim that near-verb items require rerepresentation to be accepted. In contrast, the near-noun and syn-noun items showed no reliable difference, $t(46) = .53$, $p > .13$. (There were too few acceptances of far-verb items to permit statistical comparison with the near-verb items.)

With this larger data set, we also examined rejection latencies. Near-verb items ($M = 2{,}245$; $SD = 760$) took nonsignificantly longer to reject than far-verb items ($M = 1{,}903$; $SD = 630$). The remaining item types (syn verbs and all three noun-pair types) had too few rejection responses to evaluate. Far-verb items were easy to reject (86% of the time) as predicted, and, at least qualitatively, showed the fastest mean RT for rejection. This fits with what a rerepresentation account would predict, because any attempt to rerepresent the far-verb pairs as partly identical should terminate quickly because of their extremely low degree of potential overlap.

One difficulty with considering only either Yes RTs or No RTs is that (as predicted) the near-verb items are fairly evenly mixed in the two kinds of responses, so there is effectively only half as much data in that cell as in the other two. Another way to look at the RT data is in terms of dominant response: *yes* for the syn-verb pairs, *no* for the far-verb pairs, and a mix of *yes* and *no* for the near-verb pairs. Fig. 2 shows the latency data plotted in terms of the dominant response produced for each item type. For all of the noun-change items, acceptance was the dominant response. For the verb-change items, acceptance was dominant for syn verbs, rejection was dominant for far verbs, and the two response types were evenly balanced for near verbs (therefore all responses are included). The figure shows a pattern of fast acceptances for syn verbs, fast rejections for far verbs, and slower responses (both acceptances and rejections) for near verbs. For near verbs, the mean acceptance latency ($M = 1{,}970$) was significantly longer than that for syn verbs ($M = 1{,}629$), $t(45) = -3.95$, $p < .001$, and the mean rejection latency ($M = 2{,}245$) was significantly longer than that for far verbs ($M = 1{,}836$), $t(43) = 4.71$, $p < .001$.[8] This pattern fits with a rerepresentation account in which clearly matching or nonmatching relations are dealt with quickly, whereas potentially overlapping relations (e.g., the near verbs) require extended processing time.

The far-noun items merit further consideration because the less dramatic, but reliably lower, rate of analogical acceptance on these items (as compared to the near nouns and syn nouns)

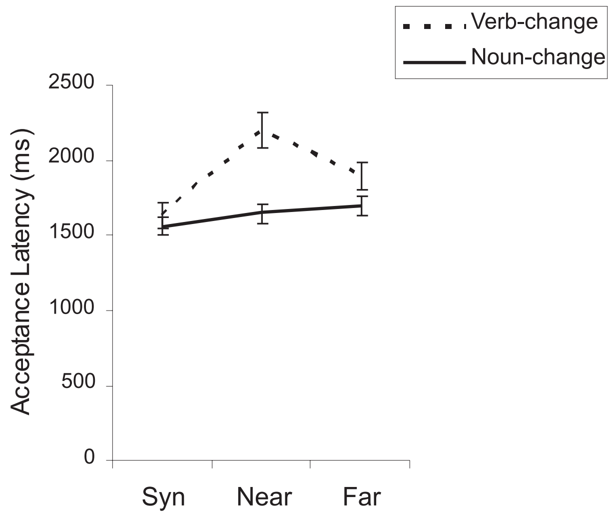

Fig. 2. Mean latency for dominant responses in Experiment 2.

runs against the strongest version of the relational focus prediction. SMT states that objects are considered and play a role in the mapping process, but will have much less influence on the final interpretation and evaluation of the analogy than will the relational match. Therefore, the pattern of results in which a complete semantic mismatch on objects acts to moderate the consistency of analogical acceptance is no great surprise. However, there is an intriguing alternative conception of this effect: The reduction in analogical acceptance of far-noun items may in fact be at least partly attributable to a diminution of the *relational* match. Prior studies of sentence interpretation have shown that verb meanings tend to adapt to noun meanings under conditions of semantic strain (Gentner, 1981; Gentner & France, 1988; Kersten & Earles, 2004; Reyna, 1980); and even mathematical relations may be interpreted differently when combined with different objects (Bassok, Chase, & Martin, 1998). Gentner (1981) proposed that the mutability of verbs during comprehension contributes to their relatively high degree of polysemy. For example, *honoring a soldier* and *honoring an agreement* bring out different aspects of the verb and have different inferential implications. Consider another example from our materials: *shortening the pants* versus *shortening the paper.* Here, we conjecture that the verb's meaning adapts to that of its noun argument in that different actions must be inferred in the two cases to achieve the verb's result.

This line of reasoning implies that the encoding of the verb meaning in the far-noun condition may differ considerably from the encoding in the standard sentence. Thus even though the surface verbs match, the actual relational representations only partially match, weakening the relational overlap. If this reasoning is correct, then we should find longer RTs for far-noun items when they are accepted. Indeed, pairwise comparisons revealed reliably longer mean RTs in the analogical acceptance of far-noun items as compared to syn-noun items, $t(46) = 3.11$, $p = .003$, and as compared to near-noun items, $t(46) = 2.58$, $p = .01$.

3.2.1. Justifications of accepted analogies

The goal of collecting justifications was to discover whether participants' use of language suggested any shift in the representational content, particularly for verbs in the near-verb condition. The justifications for accepted analogies were scored for redescription of the nouns and verbs in the sentences. To make the scoring process as objective as possible, redescription of the original stimulus was operationalized in terms of (a) new descriptive language; and (b) coordinated descriptive language. *New-language redescriptions* were defined as any expression about the sentence using language not present in the stimulus (excluding the generic terms *thing, object, action*). Examples that were scored as new-language redescriptions include

made/cooked → preparing a meal
kite/airplane → something which flies in the sky

In these two examples, the participant introduced new language that is distinct from the initial sentences to articulate the commonality. *Coordinated-language redescriptions* were defined as cases of one concept being expressed in terms of the other plus some variation, such as

ran/jogged → running is fast jogging
mall/store → a mall contains stores

In these examples a match is justified through the use of a coordinated description of one keyword in terms of the other. However, the vast majority of redescriptions were of the new-language variety.

The results shown in Table 5 show that redescription is a common basis for justification of analogical relatedness. Verb-change items were justified with redescriptions of the relational match, whereas noun-change items were chiefly justified with redescriptions of the object match. There is a striking asymmetry in these data: Whereas for noun-change pairs, verb redescriptions are fairly common, noun redescriptions virtually never occur for verb-change pairs. The high rate of redescription of verbs in the verb-change items bears out the importance of establishing common relational structure in analogical relatedness. The fact that near- and far-verb items are especially likely to be redescribed is consistent with the possibility that participants are rerepresenting meanings to achieve common conceptual relations and arrive at an analogical alignment. In cases where participants did not provide any redescription in the artic-

Table 5
Percentage of redescriptions in justifications of accepted analogies

	Verb Redescriptions (%)	Noun Redescriptions (%)
Verb-change		
Syn	44	1
Near	60	0
Far	53	0
Noun-change		
Syn	9	33
Near	17	37
Far	20	18

ulation of their justification, most of the acceptances were explained by statements to the effect that the two stimulus sentences had the same or similar meanings: for example, "the actions are the same" or "*surveying* and *inspecting* have similar meanings."

As a cautionary note, we cannot be sure that redescriptions reflect the mapping process in the analogical acceptance task; they could be the result of processes specific to the justification task. Nevertheless, we believe that there is likely to be a substantial overlap between the commonalities named in the justifications and those experienced during the analogical acceptance task.

There are several other interesting features of the data representation. Near-verb items showed the highest rate of verb redescription, which supports the representation account in terms of additional processing to validate the correspondence by partial identity. We also see evidence that the acceptance of far-verb analogies may reflect some form of *radical* rerepresentation to reveal a semantic commonality between generally dissimilar predicates. Although the acceptance rate for such items is quite low, those that do occur appear to reflect the discovery of a relational match rather than the abandonment of relational focus. Finally, it is notable that although noun redescription is the norm for noun-change pairs, the far-noun pairs show a different pattern: For far-noun items, the rate of verb redescription (for identical surface verbs) is at least equal to the rate of noun redescription. This is consistent with the possibility (discussed previously) that the verbs in these sentences were initially construed to fit with their noun arguments (and thus had to be reconstrued to match one another). Thus, at the conceptual level, these far-noun sentences may initially have been represented as differing in relational structure as well as in object meaning.

4. Experiment 3a

The studies so far have borne out our key hypotheses: (a) In accord with the claim of relational focus, the verb match dominates the evaluation of analogy; (b) near-verb pairs take longer to process than syn-verb or far-verb pairs, consistent with the claim that rerepresentation must occur for nonidentical relations to determine whether there is sufficient partial overlap; (c) more redescription occurs for verb-change pairs (especially near- and far-verb pairs), which is also consistent without the claim that rerepresentation is necessary to seek identical underlying relations. However, these findings are dependent on the validity of our similarity assignments. Therefore, in Experiment 3a we asked participants to rate the similarity of the pairs used in Experiments 1 and 2, to ensure that our word pairs did indeed decrease in similarity from syn to near to far. In Experiment 3b, we turn to a more central question: Is similarity like analogy? We suggested in the Introduction that similarity judgments would resemble analogy judgments in valuing relational matches; the difference, we predicted, is that object matches would also matter.

In Experiment 3a, we collected similarity ratings of the keywords (which were the only thing altered in the sentence pairs). Because it was our goal to relate the similarity findings to the analogical acceptance results, we presented the keywords (underlined) in the same sentence context as was seen in Experiments 1 and 2, and instructed participants to judge the similarity between the underlined parts of the sentences. We chose this method rather than presenting the word pairs in isolation, because, as already noted, sentence context is important in determining the derived meaning of the words. For example, *making chicken* versus *cooking chicken* would yield a different similarity judgment than *making* versus *cooking*.

4.1. Method

4.1.1. Participants

Twenty-seven undergraduate students from Northwestern University participated for course credit.

4.1.2. Materials

The stimulus materials from Experiment 2 were used.

4.1.3. Procedure

The procedure followed that of Experiment 2, except that the task instructions were to rate the similarity of the two underlined keywords in the sentences on a scale from 1 (*low*) to 7 (*high*). The rating scale was presented on the computer screen as a horizontal series of numerically labeled buttons to be clicked with the mouse. There was no discussion of analogy nor were analogical practice items used. The instructions emphasized that participants should base their similarity judgment on the highlighted words, not the entire sentences. As in the previous experiments, both responses and latency data were collected. Participants were not told the task would be timed nor given any instructions related to speed.

4.2. Results and discussion

The results confirmed the intended manipulation of semantic similarity between item conditions (see Table 6). For both verb-change and noun-change items, the syn pairs were more similar than near pairs, which were in turn more similar than the far pairs ($p < .001$ in each pairwise test).

Table 6
Keyword similarity ratings and latencies

	Verb-Change		Noun-Change	
	M	*SD*	*M*	*SD*
Similarity				
Syn	5.66	.90	4.55	.73
Near	3.26	.95	3.72	1.26
Far	1.78	.59	1.79	.68
Latency (msec)				
Syn	3,870	936	3,862	944
Near	4,241	1,371	3,908	1,041
Far	3,864	942	3,718	1,038

4.2.1. Response latencies

The RT data should be seen as ancillary, because participants were not told they would be timed nor asked to respond quickly. Also, in a rating task on a 1 to 7 scale, it is difficult to know how much time is spent processing the stimulus versus settling on a decision about which rating to give. Furthermore, the data were collected with a mouse click over a set of buttons, which is not optimal for exact measurement of RT. For these reasons we saw no basis for eliminating any data points from the analysis as outliers. Keeping in mind these due considerations, we tested whether near-verb items would take longer to process than syn-verb items.

Near-verb items did take longer than syn-verb items, which is again consistent with the rerepresentation account, $t(26) = 2.43$, $p = .02$. No corresponding difference was found between near-noun and syn-noun items, $t(26) = .32$, $p > .7$. In fact, the mean latency for the near-verb items appears to stand dramatically apart from every other cell in the design, suggesting that some additional processing is invoked particularly in the analysis of near-verb items. The evidence collected here speaks against a decision-process interpretation of slow RTs for near-verb items in Experiments 1 and 2 (i.e., that slower responses arose due to an inability to decide between acceptance and rejection for items that fall at the boundary) because ambiguous items have a natural place in a rating scale, whereas they do not in a binary forced-choice judgment. It is also of interest to note that the fastest responses of any item type are found for far-noun items. This suggests that the longer latencies for analogical acceptance of far-noun items in Experiment 2 may be attributable to the impact of these semantically distant objects in constructing or evaluating differentiated senses of the verb rather than additional processing of the object match itself.

4.2.2. Summary

The similarity results make clear that the keywords in Experiments 1 and 2 functioned as the experimenters intended—as levels of semantic similarity. The dominance of relational content in analogical acceptance can therefore be clearly attributed to relational focus. The keyword similarity ratings do raise one potential concern because the gap between syn- and near-item similarities is considerably larger for verb-change items than it is for noun-change items.[9] This raises the possibility that the steeper drop in analogical acceptance for decreasing similarity for verbs than for nouns results simply from a greater differential in the similarity levels being traversed. To evaluate this possibility, a secondary analysis (using data from Experiments 2 and 3a) was performed on the 10 items with the largest difference between the syn-noun and near-noun item similarities, as well as a matched set of 10 sentence pairs with an equivalent difference between syn-verb and near-verb similarity. The pattern of analogical acceptance reported previously was fully preserved on these matched sets. That is, for the 10 item sets with the largest difference in similarity between the syn and near nouns, the pattern for verb change showed a steep drop across the syn, near, and far levels of semantic similarity ($M = .96, .61, .20$); and, in contrast, analogical acceptance was fairly flat across noun change ($M = .98, .96, .85$). For the matching subset of 10 items that showed an equivalent difference in similarity between syn and near verbs, we again found that analogical acceptance varied across verb similarity ($M = .95, .50, .11$) but not across noun similarity ($M = 1.00, .95, .86$). These results suggest that the finding of relational focus from Experiments 1 and 2 cannot be attributed to differences among the levels of semantic similarity across the noun-change and verb-change stimuli.

5. Experiment 3b

We now turn to the third claim raised at the outset: that literal similarity is evaluated in the same manner as analogy, except that object matches also contribute to goodness of match. If this holds, then relational matches should be more strongly weighted than object matches in the evaluation of literal similarity. Such a finding would support the claim that "similarity is like analogy" (Gentner & Markman, 1995) and would also be consistent with the predictions of SME. As noted previously, this claim, like that of relational focus, has received some support (e.g., Gentner et al., 1993; Holyoak & Thagard, 1995; Kokinov & French, 2002; Medin et al., 1993), but prior studies involved large sets of relations and small sets of objects. This method allows us to compare the two kinds of match more evenly.

In this experiment, we collected similarity ratings on the entire sentences presented as in Experiments 1 and 2. However, instead of a forced-choice judgment of analogical acceptance, participants were asked to rate the similarity. In contrast to Experiment 3a, participants rated the similarity of the whole sentence, not just the pairs of keywords. We used ratings of similarity rather than a yes–no task as in Experiments 1 and 2 because informal questioning revealed that participants found this continuous rating more natural for similarity. In addition, the use of ratings allows a potentially informative comparison with the results of Experiment 3a.

5.1. Method

5.1.1. Participants

Thirty-one undergraduate students from Northwestern University participated for course credit.

5.1.2. Materials

The stimulus materials from Experiment 2 were used.

5.1.3. Procedure

The procedure exactly followed that of Experiments 1 and 2 except that as the second sentence appeared, participants were asked to rate the similarity of the sentences by clicking with the computer mouse along a horizontal scale from 1 (*low*) to 7 (*high*). The keywords were not highlighted and, in accord with the procedure used in the analogy studies, participants were not instructed to focus their attention on any particular part of each sentence.

5.2. Results and discussion

The similarity results for the full sentences (see Table 7) show a pattern of relational focus similar to that observed for analogy in the earlier studies (but very different from the individual keyword similarity ratings from Experiment 3a). Similarity was governed to a much greater

Table 7
Sentence similarity ratings and latencies

	Verb-Change		Noun-Change	
	M	*SD*	*M*	*SD*
Similarity				
Syn	5.07	.97	4.52	.74
Near	4.25	.68	4.72	.81
Far	3.48	.90	3.68	1.03
Latency (msec)				
Syn	4,560	992	4,612	979
Near	4,798	991	4,692	1,012
Far	4,725	930	4,811	1,026

extent by changes in the verb than by those in the noun. Syn-verb items ($M = 5.01$) were rated as more similar than near-verb items ($M = 4.25$), $t(30) = 5.30$, $p < .001$; however syn-noun items ($M = 4.52$) were not more similar than near-noun items ($M = 4.72$). In fact, there was a small, but significant effect in the opposite direction as discussed later.

As expected, object matches did enter into the similarity judgments. In contrast to the pattern for analogical judgments, substantial levels of similarity were still observed even when there was a relational mismatch (for far-verb items, $M = 3.48$). The role of object match was also made clear by the fact that noun-change items with identical verbs were rated as less similar than syn-verb items (with identical nouns). In addition, there was a substantial drop in similarity between near-noun ($M = 4.72$) and far-noun ($M = 3.68$) items, $t(30) = 7.71$, $p < .001$. This is a more dramatic effect than the slight decrease in analogical acceptance observed in the prior experiments, consistent with the view that object matches matter more in literal similarity than in analogy.

As noted previously, syn-noun items ($M = 4.52$) were rated slightly *less* similar than near-noun items, $M = 4.72$, $t(30) = 2.49$, $p < .02$. This reversal is not attributable to the nouns by themselves; the results of Experiment 3a showed a mean noun similarity rating ($M = 4.55$) for syn-noun items, significantly higher than for near-noun items ($M = 3.72$). A possible explanation for this reversal lies in the interpretative process brought to bear when full sentences with synonymous nouns are compared. For example, although *dog* is more similar to *puppy* (the syn noun) than to *bird* (the near noun), *abandoned the dog* feels more similar to *abandoned the bird* than to *abandoned the puppy;* the act of abandoning takes on different force for a young creature (where it suggests a deliberate death sentence) than for an adult creature. In other words, for a few of our sets, the difference in the nouns apparently led to a difference in the overall event construal (Gentner & France, 1988). As another example, *butler* and *doorman* (the syn noun) are quite related in meaning, but when evaluated in the context of the verb, they may be thought to diverge: *Questioned the butler* may evoke a crime scene, whereas *questioned the doorman* might suggest a more prosaic inquiry about gaining entry. Such differences are not rendered salient when the noun-pair similarity is evaluated independently, but they become crucial in comparing the whole assertion, where greater focus will be placed on the relational match.

5.2.1. Response latencies

Experiment 3b was also not designed primarily to examine response latency. Even so, we predicted elevated processing time for near-verb items as was found in each of the preceding experiments. Although there was a slight trend in this direction, the difference between near-verb and syn-verb fell short of significance, $t(30) = 1.31$, $p = .2$. This result may be due simply to lack of sensitivity in the measure. It could also reflect the lack of a triggering condition for a rerepresentation process to search for a partial match. When analogical relatedness is assessed (as in Experiments 1 and 2) or when participants are asked specifically to compare the meanings of the verbs (as in the keyword similarity task of Experiment 3a), they appear to focus strongly on finding commonalities between the verb meanings. In contrast, although relational meaning is important in judging the overall similarity of the sentences, the focus is spread over both relational and object matches. As such, rerepresentation of the near-verb items (and therefore elevated processing time) may be less likely to occur.

5.2.2. Surface similarity versus keyword similarity

Comparing the findings from Experiment 3b with those of Experiment 3a, we first note that the pattern of ratings is quite different between the experiments (as they should be, because in Experiment 3a participants were instructed to rate only the underlined text for similarity). In both the keyword and full sentence ratings, syn items (nouns and verbs) were rated as high in similarity. (Regarding the possibility of ceiling effects, the means are considerably distant from the endpoint [7] of the rating scale.) In contrast, the near and far items showed much lower similarity ratings in the keyword task than in the full sentence ratings. For example, the pair *bought the candy* and *bought the bookshelf* were more similar than were just the noun keywords *candy* and *sandwich* (or *bookshelf*) on their own. Likewise, the pair *bought the candy* and *took the candy* (or even *bought the candy* and *stepped on the candy*) were rated as more similar than the verb keywords alone.

5.2.3. Related work

One challenge to the structure-mapping account comes from Bassok and Medin (1997) who used materials similar to ours—simple sentence pairs using the verb and noun to encode relations or object—to assess how people choose between relational and object information in judging similarity. For pairs with matching verbs, the authors consider their data to be well explained by a structure-mapping account. However, they observed a pattern that is inconsistent with known frameworks for understanding similarity: When sentence pairs had matching objects and subjects, but different verbs, participants often thematically linked the sentences to achieve an integrated meaning. In these cases, participants tended to view relationally divergent sentences as good matches to one another. We did not observe this pattern in our data, probably because our materials used differently named individuals as the agent of the two sentences (Bassok and Medin used the same agent). For example, in Bassok and Medin's study, two sentences about "the carpenter" performing different actions on "the chair" invited thematic integration. In our design, the two actions would never be performed by the same individual. We strongly suspect that this phenomenon of thematically influenced similarity judgments for relationally mismatched cases may be restricted to sentence pairs in which *the same individual* is the actor in both activities.

6. General discussion

The chief goal of this research was to test the theoretical claim that relational matches are dominant in analogy. Our method was to independently vary the degree of relational and object match and observe the effect on the perception of analogy. The results of Experiments 1 and 2 show a clear relational focus in analogy judgments, consistent with the predictions of SMT As relational similarity diminished, analogy judgments declined from nearly universal acceptability for synonymous verbs to nearly universal rejection for far verbs. The pattern for nouns was quite different. There was no drop-off in analogical acceptability from synonymous nouns to near nouns; not until the lowest level of object similarity did analogical acceptability show a significant (but small) drop. Even at this lowest level, analogical acceptance remained the dominant response, at roughly 80% across the first two experiments. Thus, the degree of object match had only a minimal influence on analogical acceptance, and only in the case of the far-noun items, which were constructed for maximal semantic difference within a shared sentence frame. Even identical objects were insufficient to support analogical acceptance of sentence pairs that lack relational commonality, as demonstrated in the far-verb case.

Relational focus has been claimed to be a signature phenomenon of analogy (e.g., Gentner, 1983; Holyoak et al., 2001). But the studies that support this claim have typically involved rich, systematic relational structure and a relatively small number of entities. These kinds of systematic structures are typically considered to be excellent analogies, and they show strong relational focus. But the observed focus on the relational structure could simply stem from the greater number of relational matches. In these studies we created an even playing field, and the results clearly show relational dominance. Further, these studies probably underestimate the degree of relational focus in analogical processing, because our materials contained only first-order relational matches, with no higher order structure.

Our results indicate that people are willing to call a pair *analogous* if and only if they find a sufficient relational match. What our results do not show is that the process of analogical matching depends only on relational matches. As noted previously, the process model embodied in SME assumes that all matches between the base and target construals enter into the alignment process and compete for inclusion in the final interpretation (Forbus et al., 1995). This assumption is consistent with psychological evidence that object matches enter into online alignment processes (Goldstone, 1994). In this study, the fact that pairs with synonymous nouns and verbs were the fastest to be accepted bears out the structure-mapping prediction that literal similarity matches are the easiest and most natural matches to compute (because the object matches support the relational matches). Further evidence for the role of object matches in online processing comes from studies that use the cross-mapping technique (Gentner & Toupin, 1986): When object matches are inconsistent with relational matches, they sometimes win out (Keane et al., 2001; Krawczyk, Holyoak, & Hummel, 2004; Markman & Gentner, 1993). The shallower the relational structure and the greater and more distinctive the local object matches, the more likely it is that the overall mapping will be based on object matches (Markman & Gentner, 1993; Paik & Mix, 2005). But in that case, the pair will not be judged analogous.

These findings also provide strong evidence that analogies are made at the level of conceptual identity between relational content. Lexical matches are not required for analogical correspondence; the syn-verb items are almost uniformly taken to be analogous. Germane to this point are findings from a separate investigation we have conducted in which a set of catch items were added to this set of stimulus materials. These items included lexical, but non-conceptual, verb matches (e.g., *punch the bully* vs. *punch the clock*). Such items were rejected as potential analogies.

6.1. Similarity

A further goal of the research was to determine the role of relational matches in the perception of similarity. Our findings add to the accumulating evidence that "similarity is like analogy" (Gentner & Markman, 1995; Medin et al., 1993). The patterns for sentence similarity fit the theoretical prediction that common relations matter most for literal similarity, but object matches contribute as well. That both relational structure and object matches contribute to similarity may account for its polymorphous qualities (e.g., Goldstone, 1995; Medin et al., 1993). People experience a clear sense of similarity when given pairs that match on all fronts; but pairs that match well in either relational structure or object attributes can also be perceived as similar.

6.2. Rerepresentation

A key theoretical question in the analogical literature is whether comparison processing can lead to new representations (French, 1995; Gentner et al., 1995; Hofstadter, 1995; Novick & Hmelo, 1994; Yan et al., 2003). Our results are consistent with this possibility. One indication that rerepresentation was occurring are the justifications provided in Experiment 2 for the accepted analogies. People were extremely likely to redescribe verbs by way of justifying an analogy, and this was especially true for the less closely matching pairs (the near and far verbs)—suggesting that acceptance of these pairs involved rerepresentation to find common relational structure. Of course, justifications after the fact are not conclusive, but the results are certainly suggestive of rerepresentational processes.

Another line of support for representation is the pattern of RTs in Experiments 1 and 2. The RTs for analogical acceptance of verbs showed an inverted *V* pattern: fast *yes* responses for synonymous verbs, fast *no* responses for far verbs, and slow responses that are a mixture of *yes*es and *no*s for the near verbs. This pattern of RTs for the verbs suggests a rerepresentation process in which relational identities are discovered by semantic analysis of nonidentical relational predicates during the mapping process. Because the near-verb matches require further processing to determine whether one can arrive at identical conceptual relations, they are accepted more slowly than syn-verb matches and rejected more slowly then far-verb matches.

6.3. Implications for other models

A gratifying degree of convergence among analogical models has occurred over the last decade. The prediction that objects as well as relations enter into the mapping process, as suggested by these results, is made by ACME (Holyoak & Thagard, 1989), associative memory-based reasoning model (Kokinov & Petrov, 2001), connectionist analogy builder (CAB; Larkey & Love, 2003), incremental analogy machine (IAM; Keane & Bradshaw, 1988), and LISA (Hummel & Holyoak, 1997), as well as by SME (Gentner et al., 1993). The prediction that relational structure (if present) will dominate in the final interpretation is less universal; it is shared with CAB and, under some conditions, LISA.[9] In the ACME model, structural consistency is only a soft constraint—with the result that ACME can produce structurally inconsistent mappings (Holyoak & Thagard, 1989; see also Hummel & Holyoak, 1997). This means that it may fail to show relational dominance; in addition, its pattern of inferences can differ greatly from that of humans (Markman, 1997). IAM also can fail to capture systematic structure, because it operates incrementally, beginning with a promising match and adding others as it goes. Depending on which match it begins with, it may or may not capture the maximal match.

Available models also differ in whether and how they deal with rerepresentation. Most accounts fall into one of two classes: (a) those that rely strictly on identity for local matches and therefore fail to show the required flexibility; and (b) those that allow matches based on similarity. The difficulties inherent in the precomputed similarity table approach have been discussed previously. Alternatively, similarity can be computed on-the-fly by models that routinely encode predicates and objects in terms of compositional elements (rather than using symbolic tokens). For example, LISA employs distributed representations that are activated according to temporal synchrony. Such a mechanism supports great flexibility, but it does not make the prediction that rerepresentation is a *selectively* activated process—a process that requires additional processing time when engaged. The environmental model of analogy (Ramscar & Yarlett, 2002) uses latent semantic analysis vector representations to allow flexible matching. This has the advantage of providing a neutral source of representations, but the approach appears to match human performance only in its patterns of analogical retrieval, not in the mapping process. In sum, the best account of these data can be made in terms of a strict identicality approach, such as that used in SME, but supported by a mechanism of selective rerepresentation. A decomposition-based approach to rerepresentation appears most promising, but the use of external connections to a semantic network of hierarchical relations (Falkenhainer, 1990; Thagard, Holyoak, Nelson, & Gochfeld, 1990) is also a possible mechanism.

Finally, we might ask whether a featural model can handle these results. The general form of the inverted-*U* pattern of RTs—fast *yes*es for close, fast *no*s for far, and slow mixed responses for intermediate similarity—can be captured with a feature-intersection model, as demonstrated by Rips, Shoben, and Smith (1973). However, a featural approach has no natural way to account for relational focus and the resultant phenomena. For example, difference in the rate of acceptance between noun-change and verb-change items cannot easily be explained without invoking relational focus. Further, the inverted-*U* in RTs is observed for verb-change items, but not for noun-change items. A featural account offers no support for this distinction. Finally, it is hard to see how a featural model could predict the justification data in terms of the types and rates of redescription that were observed. Evaluating the sentence pairs based on the number of independent matching features provides no basis for representational change.

6.4. Limitations and directions

This research used both simplified materials and a rather stripped-down task. To systematically vary the type and degree of similarity but control the relative number of objects and relations, we had to use very simple sentence analogies. It is important to ask whether these results will generalize; in this respect it is reassuring that our main finding of relational focus dovetails nicely with the results from studies that have used more complex analogies. Our task was also highly simplified. In ordinary life, we normally judge the goodness of an analogy in service of some reasoning task, rather than as an end in itself as in our studies. Of course, judgments of similarity and metaphorical aptness (both related to analogical goodness) are a standard methodology in our field. Nonetheless, it will be important to test whether these results will generalize to larger tasks.

Our interest in analogy stems from its role in learning, memory, and reasoning. In these studies, our goal was to gain a better understanding of the inner workings of the mapping process: specifically, to test claims concerning the roles of objects and relations in mapping. In future research it will be important to extend this research to richer materials and more varied tasks. It is our belief, based on the evidence for systematicity in structural alignment, that the observed effects of relational focus, flexible matching, and rerepresentation will be more dramatic for analogies between larger, more structured cases. We also speculate that large, systematic mappings may yield more decisive evidence for rerepresentation. This follows from our claim that one driving force for rerepresenting a pair of predicates is the presence of other connected predicates that already match (e.g., Yan et al., 2003).

6.5. Conclusion

Our results bear out the theoretical claim that relational matches are central in the understanding of analogy. That this pattern was obtained even with the numbers of relational matches and object matches equated provides strong evidence for the primacy of relations. Further, our results suggest that when relations are similar but not identical, rerepresentation processes are engaged that find a partial match. In sum, the perception of overall similarity appears based on both relational alignment and object matches, but the perception of analogy is engendered by matching relational structure.

Notes

1. This discussion is taken chiefly from SMT (Gentner, 1983; Gentner & Markman, 1997) and its computational model, SME (Falkenhainer et al., 1986, 1989; Forbus et al., 1995; Forbus & Oblinger, 1990). However, the basic tenets are accepted by most current models of analogy (e.g., Holyoak & Thagard, 1989; Hummel & Holyoak, 1997; Keane & Bradshaw, 1988; Kokinov & Petrov, 2001; Larkey & Love, 2003; Ramscar & Yarlett, 2002).
2. To our knowledge there are no extant models that rely on lexical identity in matching.
3. In the initial version of SME (Falkenhainer et al., 1989), analogy and literal similarity were computed differently. For analogy, only relational matches entered into the mapping; for literal similarity, all types of matches entered into the mapping. This part of the theory was changed as a result of computational experiments. Our current view is that the mapping process for analogy is the same as for literal similarity; it is only in the eval-

uation step that the two diverge. Thus, SME now uses literal similarity mode for all its mappings (Forbus et al., 1995).

4. Young children, lacking deep knowledge of relational structure, often produce object-centered interpretations; for example, "Both are long and thin" as the interpretation of "Plant stems are like drinking straws" (Gentner, 1988 p. 54).
5. Indeed, it is clear that comparison processes do highlight object attributes if these are the only commonalities. For example, Gentner (1988) found that people interpret purely attributive metaphors such as "the sun is an orange" as in terms of common object attributes, such as "round" and "orange."
6. As noted previously, in SME (as in other models of analogy) it is assumed that the mental representations of (for example) sentences are encoded at the conceptual level rather than as lexical items. Thus two perfectly synonymous terms will have the same representation.
7. A further difference between the two approaches lies in which aspects of relations are represented. SME's representations aim to capture the meaning of the relation (that is, the set of assertions that the use of that relation conveys) using structured systems of subpredicates akin to those used in lexical semantics (e.g., Fillmore, 1971; Gentner, 1975; McCawley, 1968; Munro, 1975). In contrast, LISA's representations center around the roles of the relation (Doumas & Hummel, 2004).
8. An analysis using both acceptances and rejections for near verbs showed the same pattern. Note that the degrees of freedom differ slightly between the tests because some participants had no "yes," or else no "no" answers for some similarity levels.
9. LISA, like IAM, operates incrementally, and the order and weighting of its matches are determined by a complex control structure with many special conditions and over 20 free parameters (Hummel & Holyoak, 1997; Larkey & Love, 2003). Its performance with respect to relational structure depends on how these are set.

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