Relational Constraint and Format in Verbal Analogy

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Abstract

Completion of verbal analogies (e.g., PEAR : FRUIT :: HAMMER : ____) may entail mapping between corresponding elements in the source and target pairs (e.g., alignment of PEAR with HAMMER) and/or a transfer of a common relation (e.g., superordinate; PEAR as a member of the category FRUIT) between the first and second pairs. The type of analogical relation, superordinate or coordinate (i.e., category co-membership; e.g., PEAR: BANANA :: HAMMER : WRENCH) along with the number of concepts in the analogy stem (2 *vs*. 3 concepts) were manipulated to assess the effects of these factors on relational inference and transfer. Results from two experiments demonstrated higher accuracies and faster response times for analogies having a superordinate relation than a coordinate relation. Moreover, presentation of 2 rather than 3 concepts in the analogy stem yielded higher accuracies for the coordinate but not the superordinate relations. Thus, verbal analogy performance is a function of both the constraint of the analogical relation and the focus of attention on the relation via initial presentation of only the source pair in the analogy stem.

Keywords: verbal analogy; categorical relations; structure-mapping; relational transfer; relational priming.

Introduction

Most verbal analogy test items (i.e., A:B::C:D; e.g., PUPPY : DOG :: KITTEN : CAT) entail choosing the best response from among four or five answer options to complete an analogy stem, which typically contains either the first two (e.g., PUPPY : DOG :: _____ : ______ or first three (e.g., PUPPY : DOG :: KITTEN:______) terms. Sternberg (1977) described several component processes involved in solving verbal analogies consisting of: *inference* (detecting a plausible relation between the A and B terms; e.g., offspring for PUPPY and DOG), *mapping* (one-to-one alignment of the corresponding elements in each pair; e.g., PUPPY and KITTEN are both baby animals), *application* (applying the relation inferred from the A:B pair to determine the correct C:D pair), and *response* (selecting the answer that best reflects this relation rather than the answer sharing only a superficial similarity with the other terms). Since then various theories have focused on one or more of these components. For example, Gentner's (1983) structure-mapping theory focuses on the mapping component, and more recently the analogy as relation priming (ARP) model (Leech, Mareschal, & Cooper, 2008) focuses on the inference and application components (collectively, relational transfer). Others have noted that mapping and relational transfer are not mutually exclusive, but rather are interdependent and occur in parallel rather than sequentially (Petrov & Kokinov, 1998; Ripoll, Brude, & Coulon, 2003).

Though analogical reasoning entails both mapping and relational transfer, the relative reliance on one of these processes over the other may depend on characteristics of the analogy itself as well as the analogical task. The purpose of the current study was to systematically investigate two often overlooked factors that influence relational transfer in verbal analogy, namely, the degree of relational constraint (high or low; Experiments 1 and 2), and the analogy stem format (inclusion of 2 or 3 concepts; Experiment 2). High constraining relations are those for which the relation in the source pair constrains the possible D terms. For example, in a superordinate categorical relation of the form "exemplar : category" (e.g., HAMMER : TOOL), the second term is constrained to denote the category to which the first item belongs.

Analogical reasoning is influenced by some combination of the four componential processes (inference, mapping, application, and response). Therefore, in order to better focus on factors thought to primarily affect relational transfer, it is necessary to control or minimize the influence of analogical variables affecting other component processes (e.g., the effects of semantic similarity on response). Hence, relational constraint and format along with other important factors (e.g., semantic distance) are briefly reviewed within the relevant component processes of mapping, relational transfer, and response.

Relational Roles and Similarity in Mapping

According to structure mapping theory (Gentner, 1983), source pair concepts are mapped onto their corresponding target pair concepts. For example, in the analogy, PUPPY : DOG :: KITTEN : _______, PUPPY is mapped onto KITTEN, and DOG is mapped onto the missing term). This one-to-one mapping process narrows down the possible relations that may be transferred from source to target. PUPPIES and KITTENS are both young animals, so then the transferred relation may be "X is the offspring of Y." Source and target pairs may reflect the same or similar semantic domains (e.g., TUXEDO : GROOM :: GOWN : BRIDE; Green, Fugelsang, & Dunbar, 2006) or different domains as in the current study (e.g., CAR : VEHICLE :: FOOTBALL : SPORT). Analogical theories posit a mapping process between corresponding elements in the source and target (e.g., TUXEDO and GOWN) that is aided by superficial similarity (i.e., shared features; Gentner 1983; Holyoak & Thagaard, 1997) and that occurs effortlessly without conscious awareness (Gentner & Markman, 1997; Hristova, 2009).

However, any one-to-one mapping in between-domain analogies would be based solely on the respective relational roles shared by the corresponding elements (Green et al., 2006). For instance, in the between-domain analogy, PEAR : FRUIT :: HAMMER : TOOL, both PEAR and HAMMER are members of their respective categories, and thus the more general *exemplar* relational role binds to the corresponding concepts PEAR and HAMMER (Doumas, Hummel, & Sandhofer, 2008; Estes & Jones, 2008; Holyoak & Thagard, 1997; Holyoak & Hummel, 2008; Hummel & Holyoak, 1997, 2003; Rein & Markman, 2010; Ripoll, 1998). In turn, the corresponding terms would have to be mapped (aligned) based on their more general common relational roles (e.g., exemplar and category label), which would entail a very high degree of relational abstraction. Although abstraction of such higher-order relations is certainly possible (Kotovsky & Gentner, 1996), a more parsimonious explanation is a greater ease in relational inference and transfer for the more constraining relations. In the current study, between-domain analogies were used so that any potential mapping process would be based solely on common relational roles (e.g., exemplar) bound to the corresponding concepts (e.g., PEAR and HAMMER) rather than on superficial similarity between these A and C terms.

Relational Constraint in Transfer

Sternberg and Nigro (1980) found that some analogical relations (e.g., antonyms, functional relations) yielded better performance than other relations (e.g., synonymous; see also Spellman, Holyoak, & Morrison, 2001, Table 3). One likely reason for this finding is that antonyms and functional relations are more easily detected and constraining than synonyms and category coordinates. To use one of Sternberg and Nigro's examples, in the analogy, WIN : LOSE :: ABOVE : _____, the antonymous relation is more easily inferred in the source pair and then constrains the D term to only one likely response (e.g., BELOW).

The current study systematically manipulated relational constraint by comparing a high- versus low-constraining categorical relation such that the A and C terms and the answer options were held constant between the two relation types. In the high-constraining *superordinate* relation, PEAR : FRUIT :: HAMMER : TOOL), the B and D terms were the respective category labels of the A and C terms, whereas in the low-constraining *coordinate* relations, the B and D terms were additional category coordinates (e.g., PEAR : BANANA :: HAMMER : WRENCH). The answer options (e.g., WRENCH, TOOL, POUND, STEEL, WOOD) were the same for each analogy with the correct answer for one analogical relation (WRENCH or TOOL) serving as the primary (most associated) distracter for the other relation.

Superordinate relations are not only more constraining but also are more accessible than coordinate relations (Schumacher, Wirth, Perrig, Strik, & Koenig, 2009). Hence, the greater accessibility of the superordinate relation may aid relational inference in the source pair, which would in turn constrain the response in the target pair. For example, the more accessible superordinate relation in the A:B source pair may be more easily inferred. Then this inferred relation would serve to constrain the D term to a category label of the C term (e.g., HAMMER : TOOL).

Additional Factors Influencing Transfer

The superficial and relational (i.e., structural) similarities between source and target also influence the likelihood of transferring a previously encountered applicable relation (Blanchette & Dunbar, 2000; Estes & Jones, 2006; Holyoak & Koh, 1987). Although relations can be detected and transferred without conscious awareness (e.g., Estes & Jones, 2006; Hristova, 2010; Schunn & Dunbar, 1996), relational priming and analogy studies using more strategic paradigms such as pre-cueing of the relevant relation (Bendig & Holyoak, 2009) or explicit pairing of prime (e.g., GLASS ROSE) and target (e.g., COPPER HORSE) combinations (Estes, 2003) yield more robust relational priming effects.

Similarly, presentation of only the source pair prior to presentation of any elements from the target pair should serve to focus attention on the relation in this source pair (Cho, Holyoak, & Canon, 2007). In Experiment 2, we sought to manipulate the amount of attention on the relation in the source pair by varying the format of the analogy stem between two (A:B::__:__) and three concepts (A:B::C:__).

Semantic Distance and Response

A closer semantic distance between the C term and the correct D term in comparison to that between the C term and the distracter items (i.e., foils) facilitates selection of the correct answer (Morrison et al., 2004). Likewise, the semantic distance between the A : B and the C : D pairs as measured using latent semantic analysis (LSA; Landauer, Foltz, & Laham, 1998; http://lsa.colorado.edu), facilitates analogical verification with shorter verification times for semantically closer within-domain analogies than more distant between-domain analogies (Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010). As described in the Materials subsection, the superordinate (e.g., TOOL) and coordinate (e.g., WRENCH) answer choices, which were the correct answer or primary foil on each analogy, were equivalent in semantic distance to the C term (e.g., HAMMER). Hence, verbal analogy accuracies for each of the categorical relations were not biased by a closer semantic distance for one relation over the other.

Experiment 1

The purpose of Experiment 1 was to systematically compare the verbal analogy performance between high constraining superordinate (e.g., PEAR : FRUIT) and low constraining coordinate (e.g., PEAR : BANANA) categorical relations.

Method

Participants. Wayne State University undergraduates (N = 152; 62% female) ages 18 to 49 (M = 22.09, SD = 5.42) participated for partial course credit. A subset of 42 participants also completed an established analogical reasoning test in order to validate that the items created for the experiment reflected analogical reasoning.

Materials. Items consisted of 20 superordinate and 20 coordinate categorical analogies of the form A:B::C:____. Categories and exemplars were sampled from the Van Overschelde, Rawson, Dunlosky (2004) category norms such that each source and target pair represented a different category and no categories were repeated among the 20 items. Each analogy had the same A and C terms (e.g., PEAR and HAMMER), but different B terms to produce the superordinate (e.g., PEAR : FRUIT) and coordinate (e.g., PEAR : BANANA) relations in the source pairs (see Table 1 for additional examples). Both categorical relation conditions had the same five numbered answer options which included the superordinate (e.g., TOOL) and coordinate (e.g., WRENCH) answers as well as associates or properties of the C term (e.g., WOOD, POUND) or words that could be relationally integrated with the C term (i.e., a HAMMER *composed of* STEEL; Estes & Jones, 2009). The superordinate and coordinate choices were either the correct answer or the primary distracter depending on the source pair relation. Participants completed 10 coordinate analogies and 10 superordinate analogies. Across two experimental lists, each item was represented with its superordinate and coordinate B and D terms. Across the 10 items for each relation, correct answer choice numbers were evenly distributed among the five possible answer choice numbers (e.g., answer choice #3 was the correct answer for two of the superordinate items and for two of the coordinate items). Across the two lists, the correct answer was the same number item for each relation (e.g., answer #4 was TOOL for the superordinate on one list and WRENCH for the coordinate on the other list).

Table 1: Additional Verbal Analogy Examples.

A term	B term Superord., Coord.	C term	D term Superord., Coord.
ANT	INSECT, MOSQUITO	CARROT	VEGETABLE, SPINACH
CANOE	BOAT, YACHT	OAK	TREE, MAPLE
SALMON	FISH, TUNA	YELLOW	COLOR, GREEN

To control for the influence of semantic distance (Morrison et al., 2004; Green et al., 2010), semantic similarities (LSA cosines) between the C and each answer choice as well as the semantic distance between the A:B and C:D pairs were assessed. LSA cosines were equivalent between the C term (HAMMER) and each of the categorical D terms (e.g., superordinate: e.g., TOOL, $M = .416$, $SD = .239$; coordinate, e.g., WRENCH, $M = .462$, $SD = .269$), $t(19) = 1.11$, $p = .28$. However, the mean LSA value for the three remaining foil items ($M = .288$, $SD = .163$) was lower than that of the superordinate, $t(19) = 2.52$, $p < .05$, and the coordinate, $t(19) = 2.99$, $p < .01$, answer choices, hence participants were more likely to select one of the categorical relations than any of the three other foils (Morrison et al., 2004). Because the analogies consisted of between-domain pairs, the pairwise semantic distance between the A:B and C:D pairs were low and did not differ between the superordinate ($M = .066$, $SD = .038$) and coordinate ($M = .089$, $SD = .087$) conditions, $t(19) = 1.47$, $p = .16$.

To validate the items created for this experiment, a subset of 42 participants completed 18 items from the Air Force Officer Qualifying Test (AFOQT; Berger, Gupta, Berger, & Skinner, 1990). These 18 items were the same subset of items as used in previous studies examining the interrelationships between measures of cognitive abilities (Unsworth, 2010). Like the items used in the experiment, there were five answer options per item. The higher level of required vocabulary knowledge likely contributed to lower accuracies ($M = .40$, $SD = .16$) on the AFOQT measure compared to the overall mean for the experimental items ($M = .62$, $SD = .22$). Nevertheless, correlations were indeed reliable between the proportion correct on the AFOQT and the superordinate items ($r = .41$, $p < .01$), as well as between the AFOQT and coordinate items ($r = .43$, $p < .01$).

Procedure. Participants were given the following instructions.

> For each analogy, select the term from the five answer options that produces the same relation in the second pair of words as found in the first pair. For example, for the analogy HAND:GLOVE :: FOOT : ____, the correct answer is SOCK, since a SOCK is worn on one's foot just as a GLOVE is worn on someone's HAND. Each answer option will appear one at a time, and only after all the answer options have been presented will you be able to indicate your answer by typing the corresponding number for that answer on the numberpad. Though we are most interested in your accuracy, we will also be recording your response times, so please indicate your answer as quickly as possible without sacrificing your accuracy.

Verbal analogy stems were horizontally centered and presented in ALL CAPS above the vertical midpoint of the screen for 750 ms. Stems remained on the screen as numbered answer choices were presented below the stem with each choice on a separate line for 500 ms prior to presentation of the next choice. After the fifth answer choice and a delay of 500 ms, participants were prompted to "Enter the number of your answer." Response times (RTs) were recorded from this point until an answer was provided. Presentation order of the 20 analogies was randomized across participants. Following the computerized task, 42 participants were given up to five minutes to complete the paper and pencil 18-item AFOQT.

Results and Discussion

Median RTs and accuracies were assessed for each participant within each condition. Participants exhibited higher accuracies, for the superordinate ($M = .75$, $SE = .02$) than for the coordinate ($M = .49$, $SE = .02$) analogies, $F(1, 151) = 146.71$, $p < .001$, $\eta^2 = .49$. Likewise, RTs were faster for the superordinate (M = 3491, SE = 189) than the coordinate (M = 4635, SE = 224) items, $F(1, 151) = 35.59$, $p < .001$, $\eta^2 = .19$. These results replicate prior findings of differences among relations in verbal analogy (Sternberg & Nigro, 1980) and relational priming (Spellman et al., 2001), and are consistent with recent findings that superordinate relations are more accessible than coordinate relations (Schumacher et al., 2009). Because each analogy within the two relations were matched on their A and C terms and all five answer choices, the current results provide a more systematic comparison of these two widely used analogical relations.

The less constraining coordinate relation may be more susceptible to experimental manipulations that focus attention on the relation in the source pair. In contrast, inference of the more constraining superordinate relation is likely to be unaffected by such a manipulation. Experiment 2 investigates this possibility further by varying the presentation between 2 versus 3 concepts in the analogy stem.

Experiment 2

Initial presentation of only the first two terms in an analogy stem prior to presentation of the answer options would likely serve to focus attention on the relation in the source pair. Moreover, the lack of a C term in the analogy stem may prevent a potentially distracting search for semantic or structural commonalities between the source and target pairs. Effectively then, this isolated presentation of just the source pair makes the analogical selection task more like an analogical generation task, in which participants rely more on structural than superficial similarities to generate a target analog (Blanchette & Dunbar, 2000; Dunbar, 2001). Hence, accuracies were predicted to be greater for the coordinate items when only 2 concepts were presented in the analogy stem rather than 3 concepts. In contrast, given the relative ease in accessing the superordinate relation, presentation of only the first two concepts may not further facilitate relational inference.

Method

Participants. Wayne State University undergraduates (N = 174; 73% female) ages 18 to 57 (M = 21.39, SD = 7.30) participated for partial course credit. Participants were randomly assigned to either the 2 concept (n = 86) or the 3 concept (n = 88) analogy stem condition.

Materials and Procedure. The same materials and procedures were used as in Experiment 1. More time was given for the presentation of the analogy stem (1500 ms) and each answer choice (1000 ms). This was done so that participants would have sufficient time to read each paired (C:D) answer choice in the 2 concept format condition.

Results and Discussion

A 2 (analogy stem format; between-participants) × 2 (categorical relation; within-participants) mixed ANOVA was conducted with accuracies (proportion correct) and median RTs as the dependent measures. Mean accuracies for each condition are shown in Figure 1.

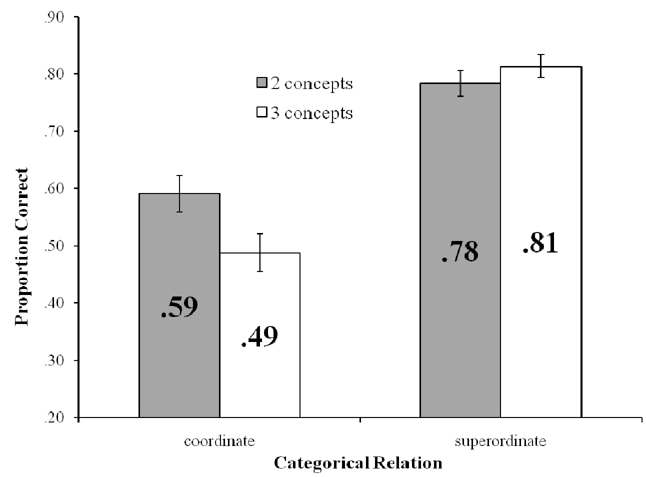

Figure 1: Proportion Correct, Experiment 2.
Error bars reflect standard errors.

As in Experiment 1, accuracies were greater for the superordinate (M = .80, SE = .02) than for the coordinate (M = .53, SE = .02) relations, $F(1, 172) = 164.09$, $p < .001$, $\eta^2 = .49$. The main effect of format was not reliable, $F < 1$, $p = .32$. As predicted, there was a reliable interaction between format and relation, $F(1, 172) = 8.92$, $p < .01$, $\eta^2 = .05$. Within the coordinate relation, accuracies were greater when only two rather than three concepts were included in the analogy stem, $t(172) = 2.08$, $p = .04$. In contrast, within the superordinate relation, format had no effect, $t<1$, $p = .32$.

Most likely due to the additional C term in the answer choices, response times were slower for the 2-concept (M = 4386, SE = 322) than for the 3-concept (M = 3094, SE = 318) analogy stem format, $F(1, 172) = 8.14$, $p < .01$, $\eta^2 = .05$. As in Experiment 1, response times were faster for the superordinate (M = 3006, SE = 231) than the coordinate (M = 4474, SE = 259) relations, $F(1, 172) = 60.85$, $p < .01$, $\eta^2 = .26$, although there was not even a hint of an interaction between format and relation, $F < 1$, $p = .94$.

Thus, results replicated the lower accuracies found for the coordinate relations in Experiment 1, and extended these findings by demonstrating higher accuracies for coordinate relations when only 2 rather than 3 concepts were presented in the analogy stem. Moreover, simply presenting only the source pair in the analogy stem served to draw attention to the relation in that pair, thereby favoring a relational transfer over an attempt to align the dissimilar A and C terms.

General Discussion

Results provided the first systematic comparison between two common analogical relations. Across two experiments, accuracies were greater for superordinate than for coordinate relations, thereby extending prior findings of superior accessibility for superordinate category information (Schumacher et al., 2009) in verbal analogy.

Notably, the slower presentation times in Experiment 2 (i.e., 1500 versus 750 ms for the analogy stem and 1000 versus 500 ms for each answer choice) did not impact the accuracies for the 3-concept stem coordinate relation (both *M*s = .49, *p* = .91), though accuracies were somewhat higher for the superordinate relations with the additional time in Experiment 2 than in Experiment 1 (*M* = .81 vs. *M* = .75, *p* = .013). So when 3 concepts were included in the analogy stem, relational transfer for coordinate relations was not aided by additional time.

The results of Experiment 2 demonstrate that presentation of only 2 concepts rather than 3 concepts in the analogy stem could facilitate performance in a verbal analogy task for some relations. From a practical standpoint, this result supports the recommendation in many standardized test preparation books to find the relationship between two of the concepts as the first step in solving the verbal analogy before reading the answers (e.g., Kaplan's Miller Analogies Test, 5th edition, 2010). Moreover, this finding suggests a couple important points about mapping versus relational transfer processes in verbal analogy. First, the availability of a third concept in an analogy stem may increase the likelihood that one may initially attempt to align the A and C terms, which is an ineffective strategy for a between-domain analogy.

Alternatively, the influence of 2 versus 3 concepts in the analogy stem also may be attributable to the accessibility and constraint of the source pair's relation. Though the current experiments compared only these two categorical relations, future studies would likely find differences between other common analogical relations (e.g., functional versus category coordinate; antonyms versus synonyms) that replicate differences found in other domains such as the greater accessibility of instrumental relations in semantic priming studies (Moss, Ostrin, Tyler, Marslen-Wilson, 1995). Instrumentally related pairs, in which the first concept is used to perform some action on the second (e.g., BROOM – FLOOR; *sweep*), and other thematically related pairs are more accessible than similarly associated categorical coordinate pairs (e.g., BROOM : MOP; for review see Estes, Golonka, & Jones, 2011). Indeed, instrumentally related items, yielded more robust priming effects (i.e., faster word recognition times) in comparison to categorical coordinates; Moss et al., 1995; Nation & Snowling, 1999). Moreover, mediated priming (i.e., faster activation of a target, STRING, following an indirectly related prime, WIND) obtained for items having an instrumentally related prime-mediator (e.g., WIND – KITE; Jones, 2010). Hence, a future experiment comparing instrumental analogies (e.g., WIND : KITE :: BOWL : SOUP) with corresponding categorical coordinate analogies (e.g., WIND : BREEZE :: BOWL : PLATE) may yield a similar result with a smaller format effect for the more accessible and constraining instrumental relations than for the less accessible and constraining categorical coordinate relations.

In sum, the current results demonstrate that focus on the source pair's relation can be accomplished by a more subtle manipulation than explicit pre-cueing of the relation (Bendig & Holyoak, 2009) or instruction to attend to a possible common relation (Spellman et al., 2001). That is, simply providing the opportunity to focus only on the relation between the A and B terms prior to presentation of the C term in the answer options increased accuracy, but only for the coordinate relation.

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