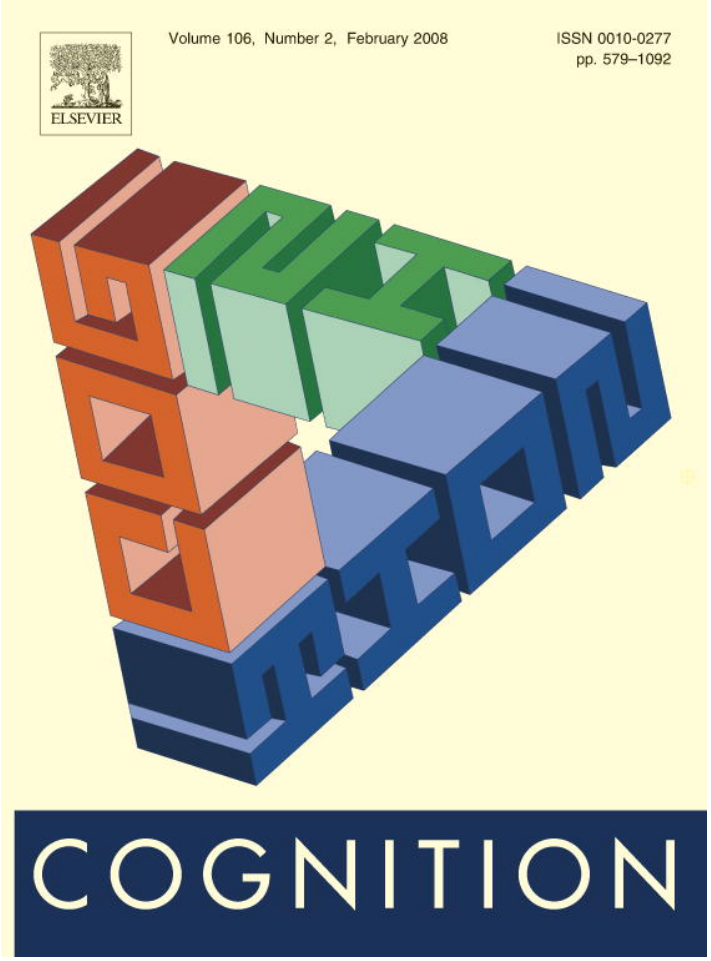

Available online at www.sciencedirect.com
ScienceDirect
COGNITION
Cognition 106 (2008) 1004–1016
www.elsevier.com/locate/COGNIT

Brief article

The Micro-Category account of analogy ☆

Adam E. Green [a,*], Jonathan A. Fugelsang [b], David J.M. Kraemer [c], Kevin N. Dunbar [c,*]

[a] *Department of Psychology, Yale University, P.O. Box 208205, New Haven, CT 06520, USA*
[b] *Department of Psychology, University of Waterloo, USA*
[c] *Department of Psychological and Brain Sciences, Dartmouth College, 6207 Moore Hall, Hanover, NH 03755, USA*

Received 4 August 2006; revised 20 March 2007; accepted 25 March 2007

Abstract

Here, we investigate how activation of mental representations of categories during analogical reasoning influences subsequent cognitive processing. Specifically, we present and test the central predictions of the "Micro-Category" account of analogy. This account emphasizes the role of categories in aligning terms for analogical mapping. In a semantic priming paradigm, a four-word analogy task was compared to two other four-word tasks. Stimuli were identical in all tasks; only the instructions given to participants differed. Participants were instructed to identify analogy relations, category relations, or conventionalized semantic relations in the four-word sets. After each four-word set, a single target word appeared and participants named this word aloud. Target words that referred to category relations in the preceding four-word sets were primed as strongly when participants identified analogies as when participants identified categories, suggesting that activation of category concepts plays an important role in analogical thinking. In addition, priming of category-referent words in the analogy and category tasks was significantly greater than priming of these words when participants identified conventionalized semantic relations. Since identical stimuli were used in all conditions, this finding indicates that it is the activation of category relations, distinct from any effect

☆ This manuscript was accepted under the editorship of Jacques Mehler.

* Corresponding authors. Tel.: +1 336 430 7097; fax: +1 203 432 7172 (A.E. Green); Tel.: +1 603 646 2998; fax: +1 603 646 1419 (K.N. Dunbar).
E-mail addresses: Adam.Green@Yale.edu (A.E. Green), Kevin.N.Dunbar@Dartmouth.edu (K.N. Dunbar).

0010-0277/$ - see front matter
doi:10.1016/j.cognition.2007.03.015

of basic semantic association, that causes analogical reasoning to prime category-referent words. We delineate how the "Micro-Category" account of analogy predicts these phenomena and unifies findings from diverse areas of research concerning analogical reasoning.

Keywords: Analogy; Categorization; Micro-Category; Priming; Facilitation; Analogical reasoning; Analogical mapping

1. Introduction

Analogies come in many different forms, ranging from the politically charged, "Iraq is like Vietnam", to the mundane, "Life is like a box of chocolates". Analogical thinking is a fundamental cognitive tool for learning, understanding, and generating novel ideas (Dunbar & Blanchette, 2001; Gentner, 1999; Holyoak & Thagard, 1995). Thus, we can gain critical insights into the way humans think and learn by understanding the mechanisms that make this tool work. While analogies can take many forms, one particularly useful approach to understanding the mechanisms of analogy is to examine four-term analogies of the form, "A is to B as C is to D". These relatively non-ornate analogies have been favored in intelligence research (e.g., Sternberg, 1977) because they simplify the process of decomposing analogy into constituent processes. Constructing or comprehending an analogy, such as "a cub is to a bear as a kitten is to a cat", requires a semantic bridge, called a mapping, between two or more systems. In this case, the mapping connects the 'cub–bear' system and the 'kitten–cat' system. Analogical mapping relies on aligning the elements of these systems appropriately (Gick & Holyoak, 1980; Markman & Gentner, 2000). In this example, cub is aligned with kitten and bear is aligned with cat.

Data we have recently obtained in convergent lines of research have pointed toward an account of analogy in which categorization (e.g., cub and kitten are young animals; bear and cat are adult animals) is a mechanism for aligning terms in analogical mapping (Green, Fugelsang, & Dunbar, 2006a; Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006b). Here, we present an account, which we call the "Micro-Category" account, which newly incorporates categorization into analogical mapping in this aligning role. We test two central predictions of this account using a semantic priming paradigm.

2. Categorization in analogical reasoning

A key question for analogy research concerns how people align the elements that make up analogies. Some previous accounts that involve alignment have addressed categorization, but these models have described categorization of whole systems (e.g., the cub–bear system and the kitten–cat system) rather than categorization of the individual component terms (e.g., cub and kitten) that make up these systems (see Fig. 1a). For example, the LISA model described by Hummel and Holyoak

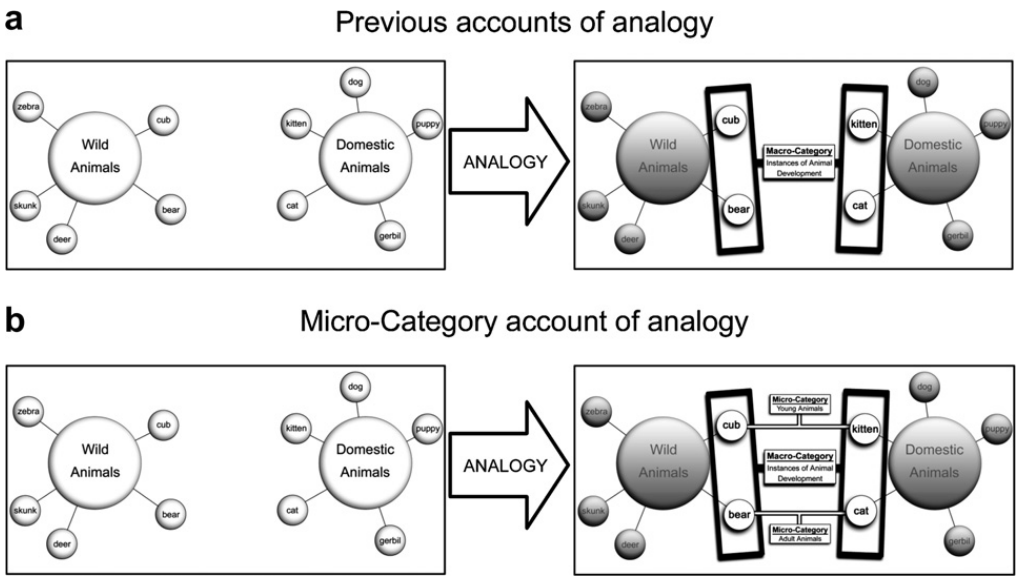

Fig. 1. Graphical depiction of the role of categorization in the Micro-Category account of analogy and in previous accounts of analogy.

(2003) predicts that category relations will be formed between whole systems that contain similar component relations. Gentner and Markman (1997) have made the related argument that determining two whole systems to be analogous is an important criterion in deciding that the two systems are members of a common category. Note that it is whole systems, rather than component terms, that are categorized in these accounts.

A distinct but non-conflicting hypothesis is that, in addition to occurring at the macro-level of whole systems, categorization also plays an important role at the micro-level within analogies. Specifically, we have obtained evidence suggesting that categorization supports analogical mapping by serving as a mechanism for aligning the elements that make up analogies (Green et al., 2006a). This suggestion is related to some previous observations that have been made in the analogy literature. For example, accounts of analogical mapping have noted that aligned terms are often terms that play similar roles (Bowdle & Gentner, 2005; Gentner, 1983; Gentner & Markman, 1997; Holyoak & Thagard, 1997; Hummel & Holyoak, 2003). Gick and Holyoak (1983) noted that "mapped elements... are typically similar but not identical" (pg. 6). In a non-analogical paradigm, Bassok and colleagues (Bassok, Chase, & Martin, 1998; Wisniewski & Bassok, 1999) demonstrated that categorically related items such as *apples* and *oranges* can be readily compared because category co-membership makes them easy to align for comparison. However, we are not aware of any empirical investigation other than Green et al. (2006a) that has identified categorization as a potential mechanism for aligning component terms during analogical mapping.

3. The Micro-Category account of analogy

The Micro-Category account is so named because it addresses small-scale categorization of individual component terms or elements within the larger process of analogical mapping. Previously, we have reported that participants take longer to name the color of a word if that word refers to a category relation between elements of an analogy that they have just processed (Green et al., 2006a). These data indicate that category relations become active during analogical mapping and interfere with color-naming for these words. In a convergent line of research, we found that cortical areas specifically associated with semantic categorization showed the same pattern of activity during analogical reasoning that they showed during categorization (Green et al., 2006b). In the present research, we build from the data that have emerged from these behavioral and brain-based investigations to newly define and test an account of analogical mapping in which categorization of component terms plays a role in analogical mapping. This Micro-Category account diverges from previous accounts of analogy that have focused on larger-scale (macro-level) categorization of whole systems. Fig. 1 presents a graphical depiction of (a) previous accounts of analogy to which the Micro-Category account adds a categorization-based delineation of alignment, and (b) the way in which categorization is hypothesized to support analogical mapping between structured knowledge representations in the Micro-Category account.

In the Micro-Category account, a reasoner's ability to recognize that the statement, "hand is to glove as foot is to sock", constitutes a valid analogy is facilitated by identifying category relations that structure the alignment of corresponding terms. Specifically, category relations exist between hand and foot and between glove and sock (they are category co-members). Thus, in this example, category relations exist where terms are aligned to correspond (e.g., hand and foot are aligned to correspond and are category co-members). However, if the example were "hand is to glove as *sock is to foot*", the alignment of terms no longer follows the category relations (e.g., hand and sock are aligned to correspond but are not category co-members) and the analogy breaks down (hand is *not* to glove as sock is to foot).

The Micro-Category account makes two central predictions. First, category relations should spontaneously become active during analogical reasoning even when the reasoner is not explicitly trying to identify category relations. Thus, it should be possible to observe priming of category relations as a consequence of processing an analogy. Second, because category relations are hypothesized to play a special role in analogical reasoning, category relations should become more active during analogical reasoning than other types of semantic processing. Thus, it should be possible to distinguish the analogy-specific priming of category relations from more general semantic-associate priming.

To test these predictions, we employed a naming paradigm. Using naming paradigms, a large body of research has found that the time it takes participants to begin reading a word is decreased when the word is preceded by a related item (see Neely, 1991, for review). With respect to the first prediction, that analogy should directly prime category relations, the Micro-Category account predicts that naming should

be faster when words that refer to category relations are preceded by analogies that involve those category relations.

With respect to the second prediction, the Micro-Category account holds that decreased response times for a target word (e.g., weapon) preceded by a four-word analogy (e.g., 'Gun:Bullet::Bow:Arrow') is due to activation of a category (*weapon*) that takes place during analogical mapping. Alternatively, these decreased response times may be the result of more general semantic association between the target word and the words in the four-word set. To test these competing alternatives, we compared response times for category-referent words when they were versus were not preceded by analogical mapping. Based on the Micro-Category account, we predicted faster response times for category-referent words when they were preceded by four-word sets in the analogy task than when they were preceded by the same four-word sets in a non-analogical task.

The use of identical stimuli in all tasks in the present research facilitates clear between-task comparisons so that we could test the two central predictions of the Micro-Category account of analogy. Additionally, to our knowledge, the predictions of the present investigation were novel in the priming literature because we used the same stimuli that elicited slower response times in our previous study of color-naming interference (Green et al., 2006a) to predict faster response times in the present study using a naming paradigm.

4. Method

4.1. Participants

Eighty-four undergraduate native English speakers (48 females and 36 males, age 18–24) took part in the investigation for course credit. Informed written consent for all participants was obtained prior to the experiment in accordance with the guidelines established by the Committee for the Protection of Human Subjects at Dartmouth College.

4.2. Materials

Stimuli in each trial consisted of a four-word set that participants processed silently followed by a single target word that participants read aloud (see Fig. 2).

Four-word sets were designed to include specific relations between words. On all TRUE trials, the relations in the four-word set were two conventionalized semantic relations (Gentner, Bowdle, Wolff, & Boronat, 2001), two category relations, and an analogy relation. Fig. 3 schematically represents the relations contained in four-word sets on TRUE trials.

All four-word sets were previously determined to be TRUE or FALSE at a level of $\geqslant$90% agreement among 27 Dartmouth College undergraduates. Additionally, Green et al. (2006a) obtained 96% correct responding using the same four-word sets,

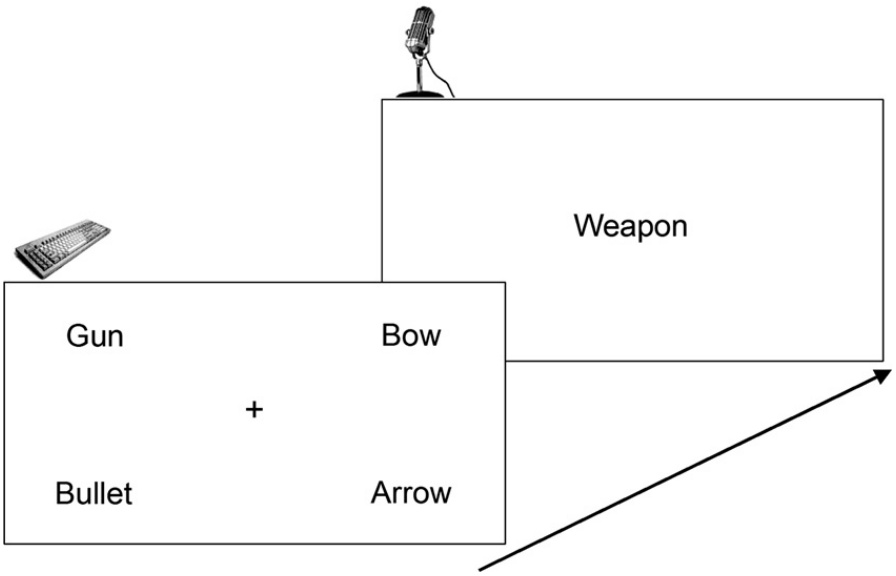

Fig. 2. Example task trial. Participants made a single True/False response to each four-word set by key press. Then, they made a verbal word-naming response to a single target word.

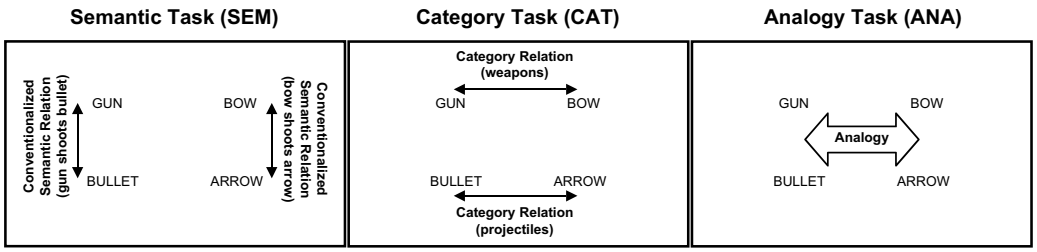

Fig. 3. Relations present in four-word sets in critical trials. In all tasks, the four-word sets in critical trials involved two conventionalized semantic relations, two category relations, and constituted an overall analogical relation. In the SEM task, participants were instructed to identify conventionalized semantic relations. In the CAT task, participants were instructed to identify category relations. In the ANA task, participants were instructed to identify analogy relations.

further validating that participants do identify the intended relations in these four-word sets.

4.3. Procedure

Participants were randomly assigned to either the Semantic task condition ($N = 28$), the Analogy task condition ($N = 28$), or the Category task condition ($N = 28$). For all three tasks, trials began with the presentation of a four-word set. In the Semantic task (SEM), participants were instructed to judge whether the four-word set included two conventionalized semantic relations (one in the left word-pair and one in the right word-pair). As in Green et al. (2006a), a convention-

alized semantic relation was defined to exist "when there is a common sense way in which two things often do, or easily could, have to do with each other." In the Analogy task (ANA), participants judged whether the four-word set constituted an analogy (between the left word-pair and the right word-pair). For example, given the four-word set, 'Gun:Bullet::Bow:Arrow,' participants judged that, since a Gun shoots a Bullet and a Bow shoots an Arrow, the two word-pairs represent the same abstract relation and are thus analogous. In the Category task (CAT), participants judged whether the top and bottom word-pairs respectively constituted words that were "both members of a common category". For example, given the four-word set, 'Gun:Bullet::Bow:Arrow,' participants judged that both Gun and Bow are weapons, and that both Bullet and Arrow are projectiles. Since stimuli were identical in all three tasks, the instruction given to participants was the only difference between the tasks.

In all trials, the four-word set was presented until participants responded TRUE or FALSE by button press. Participants were instructed that a four-word set was TRUE *if and only if* all the relations delineated in the instructions were present in the four-word set; otherwise the four-word set was FALSE. Immediately upon participants' TRUE/FALSE response, the four-word set disappeared and a single target word appeared at the center of the screen. This word remained on the screen until participants initiated a verbal response (read the word aloud). Thus, each trial involved two separate stages, silent evaluation of a four-word set, and reading aloud of a single word. Response time for word-naming was the key dependent variable.

4.4. Design and apparatus

A 3×3 mixed design was employed. The between-participants variable was task (SEM, CAT, or ANA). As explained below, the within-participants variable was whether the target word referred to the *same* relation participants had been instructed to identify, a *different* relation, or *no* relation in the four-word set. We named this variable 'reference type' (Same, Different, Unrelated). Sixty-four trials were presented to each participant. Half of these (32 trials) were TRUE trials. Of TRUE trials, half (16 trials) were critical trials in which the target word referred either to a category relation (8 trials) or an analogy relation/conventionalized semantic relation (8 trials) in the preceding four-word set. Table 1 provides examples of stimuli used in the different types of trials. A full list of stimuli is available from the authors upon request.

The reference type of critical trials was assigned as Same or Different based on the task in which they occurred. For example, when it occurred in the ANA task, the four-word set, 'Painter:Painting::Sculptor:Sculpture,' followed by the target word, 'Artist,' was classified as a Different trial. The word, 'Artist,' refers to a category relation (between Painter and Sculptor) in the four-word set rather than referring to the analogy relation that participants in the ANA condition were instructed to identify. As such, in the CAT task, this trial was classified as a Same trial. Similarly, the four-word set, 'Painter:Painting::Sculptor:Sculpture,' followed by the target word, 'Create,' was labeled a Same trial in the ANA task and a Different trial in the CAT task.

Table 1
Examples of each trial type

TRUE trials								FALSE trials			
Critical trials						Unrelated trials					
Analogy/ conventionalized semantic target word				Category target word							
Gun		Bow		Can		Bottle		Puppy		Foal		Rose		Beach
	+				+				+				+	
Bullet		Arrow		Soda		Beer		Dog		Horse		Thorn		Wafer
Shoot				Beverage				Measure				Belt		

The same trial types occurred in all three tasks (SEM, ANA, and CAT) using identical stimuli.

The target word refers to the analogy relation that participants in the ANA task were instructed to identify. That is, the abstract concept of creating is what makes the two word-pairs analogously similar in this trial. In order to allow the use of identical stimuli in all conditions without greatly increasing the number of trials, analogical relations and conventionalized semantic relations were referred to by the same target words.

On TRUE trials that were not critical trials (16 trials) and on all FALSE trials (32 trials), the target word did not refer to any relation in the four-word set. Thus, the target words in these trials represented the Unrelated reference type. Only Unrelated target words that were part of a TRUE trial (16) were used in our analyses. This was done to ensure homogeneity of variance when Unrelated trials were compared with critical trials because critical trials were always TRUE. All stimuli were presented on a G3 iMac computer running PsyScope 2.5.1 software and compatible electronic voice key (Cohen, MacWhinney, Flatt, & Provost, 1993) to receive voice input through a unidirectional dynamic microphone connected to the voice key. Speech onsets were recorded for target word naming, although no audio recording was made of the naming responses. Response times were calculated as the time lag between onset of the visually presented target word and speech onset of the naming response.

5. Results

Response times greater than 2000 ms or less than 100 ms were considered outliers and removed prior to analyses, resulting in elimination of 2.2% of responses.[1] Fig. 4 shows the mean response times for critical trials.

A 3×3 mixed ANOVA (task: SEM, ANA, CAT) $\times$ (reference type: Same, Different, Unrelated) was performed. This ANOVA revealed a main effect of reference

[1] Unfortunately, we did not record the actual spoken-word responses, which would have been informative with respect to any patterns of errors.

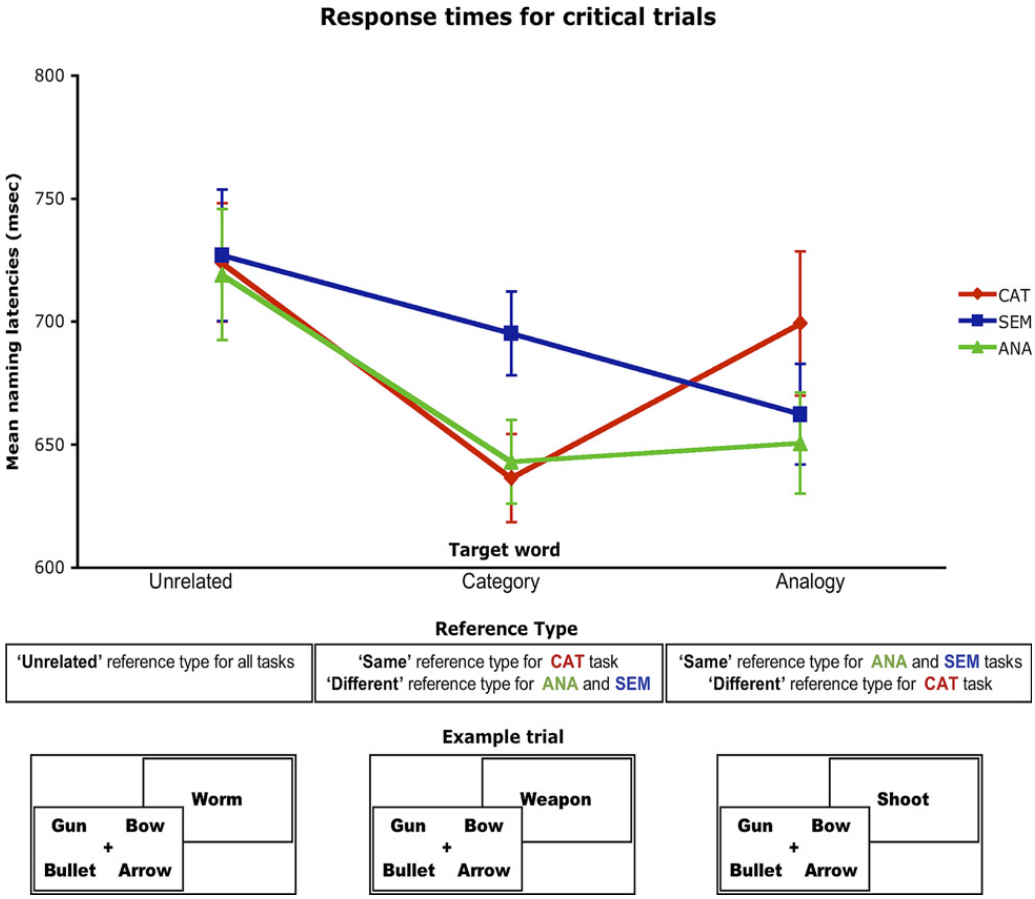

Fig. 4. Mean response times for critical trials. Error bars represent the standard error of the mean.

type, $F(2,81) = 16.55$, $MSE = 6052.04$, $\eta^2 = .17$, $p < .001$, no main effect of task, $F(2,81) = .44$, $MSE = 27952.25$, $\eta^2 = .011$, $p = .643$, and a significant interaction between task and reference type, $F(2,81) = 2.90$, $MSE = 6052.04$, $\eta^2 = .07$, $p = .024$.

In order to further examine sources of the observed variance and assess the validity of our *a priori* predictions, several *t*-tests were performed. A paired *t*-test revealed that response times for Category target words in the ANA task ($M = 643$ ms) were significantly faster than response times for Unrelated target words in the ANA task ($M = 719$ ms), $t(27) = 4.43$, $SE = 17.13$, $p < .001$, and that response times for Category target words in the CAT task ($M = 636$ ms) were significantly faster than response times for Unrelated target words in the CAT task ($M = 724$ ms), $t(27) = 5.974$, $SE = 14.66$, $p < .001$. These comparisons verify the priming of category relations in both of these tasks (ANA and CAT). Response times for Category target words were as fast in the ANA task as in the CAT task ($t < 1$), indicating that priming of category relations was as strong in the ANA task as in the CAT task.

Response times for Category target words in the SEM task ($M = 695$ ms) were significantly faster than response times for Unrelated target words in the SEM task

($M = 727$ ms), $t(27) = 2.09$, $SE = 15.13$, $p = .046$. However, response times for Category target words in the ANA task were significantly faster than response times for Category target words in the SEM task, $t(54) = 2.18$, $SE = 23.98$, $p = .034$, indicating greater priming of category relations in the ANA task than in the SEM task. Response times for Category target words in the CAT task were also significantly faster than response times for Category target words in the SEM task, $t(54) = 2.39$, $SE = 24.62$, $p = .02$.

Response times for Analogy/Semantic target words did not differ significantly between the ANA ($M = 650$ ms) and SEM ($M = 662$ ms), $t(54) = .39$, $SE = 29.72$, $p = .69$, CAT ($M = 699$ ms) and SEM, $t(54) = 1.01$, $SE = 36.40$, $p = .31$, or ANA and CAT tasks, $t(54) = 1.36$, $SE = 35.79$, $p = .18$. However, response times for Analogy/Semantic target words were faster than response times for Unrelated target words in the ANA task, $t(27) = 3.86$, $SE = 17.72$, $p < .001$, and SEM task, $t(27) = 3.56$, SE=18.16, $p < .001$, but not in the CAT task $t(27) = .78$, $SE = 31.73$, $p = .44$.

As noted above, there was no main effect of task on response times for target words. However, response times for evaluating four-word sets varied between the tasks. Response times for four-word sets were slower in the CAT task ($M = 3837$ ms) than in the ANA task ($M = 3622$ ms), $t(54) = 2.15$, $SE = 99.48$, $p = .036$, and slower in the ANA task than in the SEM task ($M = 3102$ ms), $t(54) = 6.08$, $SE = 85.68$, $p < .001$. In order to assess whether this variation in RTs for evaluating four-word sets was reflected in our measure of priming (RTs for target words), we assessed the linear correlation between RTs for each four-word set used in critical trials and RTs for the target word that followed. An items analysis collapsed across all tasks yielded no significant correlation ($r = .18$, $p = .34$). Further analyses restricted to the SEM task ($r = .11$, $p = .54$), CAT task ($r = .09$, $p = .74$), and ANA task ($r = .24$, $p = .19$) also revealed no significant correlation.

These analyses are consistent with the finding of no main effect of task on RTs for target words. They also cohere with the finding that overall mean response times for the SEM task ($M = 717$ ms), ANA task ($M = 705$ ms), and CAT task ($M = 713$ ms) were not significantly different from each other ($t < 1$ for all comparisons). Moreover, response times for Unrelated target words did not differ between the three tasks ($t < 1$ for all comparisons). Therefore, differences between the SEM task and the ANA and CAT tasks on critical trials cannot be attributed to inherent differences in speed of responding between the separate groups of participants in our between-participants design.

6. Discussion

We obtained results concerning two central predictions of the Micro-Category account of analogy using a naming paradigm to assess semantic priming. First, decreased response times for reading Category target words indicate that category relations were activated in the ANA task even though participants were not instructed to identify category relations in this task. Indeed, our data indicate that

category relations were primed as strongly during analogical reasoning (ANA) as they were when participants explicitly identified category relations (CAT). Second, the present research was able to separate the effect of category relation from the effect of semantic association. Recall that the ANA and SEM tasks involved identical target words and identical four-word sets and were therefore equated for semantic association. However, the ANA task, but not the SEM task, involved analogical mapping. If the observed priming had been the result of simple semantic association, priming in the SEM task should have been equal to priming in the analogy task. However, response times for reading Category target words were faster in the ANA task than in the SEM task. These data indicate that priming of category relations subsequent to analogies resulted from category relations becoming active during analogical reasoning and cannot be explained by simple semantic association between target words and the words in the four-word set.

Although response times for Analogy/Semantic target words in the CAT task were not significantly slower than response times for Analogy/Semantic words in the ANA and SEM tasks, they were not significantly faster than Unrelated target words in the CAT task. This indicates that analogy relations were not primed in the CAT task. It is worthwhile to note that this finding coheres with the Micro-Category account of analogy. That is, the Micro-Category account holds that categories form when analogies are evaluated, not that analogies form when categories are evaluated. Indeed, this finding is consistent with our previous finding that analogy relations are not identified when participants are instructed to evaluate category relations (not analogies) in four-word sets (Green et al., 2006a).

The data yielded by the present investigation significantly extend our previous findings concerning priming and analogy (Green et al., 2006a). Specifically, they implicate category relations, and not semantic association in general as the locus of the priming mechanism. The present findings also serve to more clearly establish the Micro-Category account as distinct from previous accounts of analogy (e.g., Gentner & Markman, 1997; Hummel & Holyoak, 2003) that have predicted macro-level categorization in analogy. We predicted that category relations would become active specifically between individual terms within the two corresponding word-pairs of the analogy. Previous accounts of analogy do not predict that category relations should become active between individual terms. This is because these accounts have delineated categorization only at the macro level between entire systems (whole word-pairs in the case of our paradigm), and not between the individual terms that compose the respective whole systems (word-pairs). As an example, for the analogy, 'puppy is to dog as kitten is to cat' (puppy:dog::kitten:cat), a macro-level account would predict activation of a category relation between the puppy–dog system and the kitten–cat system. The prediction of the Micro-Category account is distinct from this prediction. Specifically, the Micro-Category account predicts that category relations will become active between individual terms. In this case, a category relation between the term puppy and the term kitten, and a category relation between the term cat and the term dog. Macro-level accounts presented previously, have not predicted these 'micro-level' categories between individual component items.

It is important to note that the Micro-Category account does not argue against the macro-level categorization proposed in previous accounts. Rather, it introduces an additional level of categorization into the analogy process. The present study did not address the question of how categorization at the micro-level interacts with categorization at the macro-level over time as an analogy is being constructed. It is likely that any completely serial account of analogy, such as an account in which micro-categorization is completed before macro-level categorization begins, is overly simplistic. It is more likely that there is a feed-back, feed-forward relationship between categorization at the micro- and macro-level during the analogy process. Our previous findings suggest that bi-directional communication may follow the extensive feed-back, feed-forward connections between prefrontal cortex and parieto-frontal regions that we have implicated in micro-categorization (Green et al., 2006b). However, our present data do not directly speak to this point. Indeed, the Micro-Category account does not describe the full time-course of building an analogy; it simply represents the hypothesis that categories are formed between individual elements during this process.

Because the present paradigm required the same stimuli for all conditions, it was necessary to use within-domain analogies; that is, left and right word-pairs had to be taken from the same semantic domain so that intuitive category relations could be identified in the top and bottom word-pairs (see Green et al., 2006a, for a discussion of the role of category-based alignment in cross-domain analogy).

The present results provide a stronger cognitive framework in which to interpret our previous brain-imaging results. Specifically, Green et al. (2006b) found that four-word analogies processed in the ANA condition and four-word sets processed in the CAT condition showed highly similar recruitment of a parieto-frontal network of brain regions that has been previously associated with semantic categorization (Aizenstein et al., 2000; Elliott, Rees, & Dolan, 1999; Grossman et al., 2002; Koenig et al., 2005). Thus, priming of categorical relations in both the ANA and CAT tasks may reflect activity in a common cortical network involved in processing categorical relations for both analogical mapping and explicit categorization. Building from these and other previously obtained data (Green et al., 2006a), the current research newly defines and empirically establishes the Micro-Category account of analogy.

Acknowledgements

This research was funded by grants to Kevin Dunbar from the Dana Foundation and Dartmouth College. This work was also supported in part by the National Science Foundation under award REC-0634025. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation. The authors thank S. Phanitsiri and K. Smith for participant data collection, and W. Sinnott-Armstrong for helpful comments on the research.

References

Aizenstein, H. J., MacDonald, A. W., Stenger, V. A., Nebes, R. D., Larson, J. K., Ursu, S., et al. (2000). Complementary category learning systems identified using event-related functional MRI. *Journal of Cognitive Neuroscience, 12*, 977–987.

Bassok, M., Chase, V. M., & Martin, S. A. (1998). Adding apples and oranges: Alignment of semantic and formal knowledge. *Cognitive Psychology, 35*, 99–134.

Bowdle, B. F., & Gentner, D. (2005). The career of metaphor. *Psychological Review, 112*, 191–216.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments, & Computers, 25*, 257–271.

Dunbar, K., & Blanchette, I. (2001). The in vivo/in vitro approach to cognition: The case of analogy. *Trends in Cognitive Science, 5*, 335–339.

Elliott, R., Rees, G., & Dolan, R. J. (1999). Ventromedial prefrontal cortex mediates guessing. *Neuropsychologia, 37*, 403–411.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7*, 155–170.

Gentner, D. (1999). Analogy. In R. A. Wilson & F. C. Keil (Eds.), *The MIT encyclopedia of the cognitive sciences* (pp. 17–20). Cambridge: MIT Press.

Gentner, D., Bowdle, B., Wolff, P., & Boronat, C. (2001). Metaphor is like analogy. In D. Gentner, K. J. Holyoak, & B. N. Kokinov (Eds.), *The analogical mind: Perspectives from cognitive science* (pp. 199–253). Cambridge MA: MIT Press.

Gentner, D., & Markman, A. B. (1997). Structure mapping in analogy and similarity. *American Psychologist, 52*, 45–56.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology, 12*, 306–355.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology, 15*, 1–38.

Green, A., Fugelsang, J., & Dunbar, K. (2006a). Automatic priming of category concepts in analogy. *Memory & Cognition, 7*, 1414–1421.

Green, A., Fugelsang, J., Kraemer, D., Shamosh, N., & Dunbar, K. (2006b). Frontopolar cortex mediates abstract integration in analogy. *Brain Research, 1096*, 125–137.

Grossman, M., Smith, E. E., Koenig, P., Glosser, G., DeVita, C., Moore, P., et al. (2002). *Neuroimgage, 17*, 1549–1561.

Holyoak, K. J., & Thagard, P. (1995). *Mental leaps*. Cambridge, MA: MIT Press.

Holyoak, K. J., & Thagard, P. (1997). The analogical mind. *American Psychologist, 52*, 35–44.

Hummel, J. E., & Holyoak, K. J. (2003). A symbolic-connectionist theory of relational inference and generalization. *Psychological Review, 110*, 220–264.

Koenig, P., Smith, E. E., Glosser, G., DeVita, C., Moore, P., McMillan, C., et al. (2005). The neural basis for novel semantic categorization. *Neuroimage, 24*, 369–383.

Markman, A. B., & Gentner, D. (2000). Structure-mapping in the comparison process. *American Journal of Psychology, 113*, 501–538.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Erlbaum.

Sternberg, R. (1977). *Intelligence, information processing, and analogical reasoning*. Hillsdale, NJ: Laurence Erlbaum Associates, Inc..

Wisniewski, E. J., & Bassok, M. (1999). What makes a man similar to a tie? Stimulus compatibility with comparison and integration. *Cognitive Psychology, 39*, 208–238.