BRIEF REPORT

Individual Differences in the Strength of Taxonomic Versus Thematic Relations

Daniel Mirman and Kristen M. Graziano
Moss Rehabilitation Research Institute, Elkins Park, Pennsylvania

Knowledge about word and object meanings can be organized taxonomically (fruits, mammals, etc.) on the basis of shared features or thematically (eating breakfast, taking a dog for a walk, etc.) on the basis of participation in events or scenarios. An eye-tracking study showed that both kinds of knowledge are activated during comprehension of a single spoken word, even when the listener is not required to perform any active task. The results further revealed that an individual's relative activation of taxonomic relations compared to thematic relations predicts that individual's tendency to favor taxonomic over thematic relations when asked to choose between them in a similarity judgment task. These results indicate that individuals differ in the relative strengths of their taxonomic and thematic semantic knowledge and suggest that meaning information is organized in 2 parallel, complementary semantic systems.

Keywords: semantic knowledge, concept categories, thematic semantics, individual differences

The most common view of the organization of meaning information is based on categories, such as fruits or mammals, that are defined by shared features (e.g., Collins & Loftus, 1975; Markman, 1991; Mervis & Rosch, 1981; O'Connor, Cree, & McRae, 2009; Rogers & McClelland, 2004; Smith, Shoben, & Rips, 1974). In such feature-based organizations of meaning information, similarity between concepts is a function of feature overlap (e.g., Cree, McRae, & McNorgan, 1999; Mirman & Magnuson, 2009; Rogers & McClelland, 2004). An alternative organization of meaning information is based on grouping concepts thematically on the basis of participation in the same scenario or event, such as breakfast foods or objects involved in taking a dog for a walk (e.g., Estes, Golonka, & Jones, 2011; thematic groupings are closely related to ad hoc or goal-derived categories [Barsalou, 2010] but differ in that thematic relations are already established in memory). Objects that share thematic relations, such as toast and jam (eating breakfast) or dog and leash (walking a dog), typically share few, if any, features. Rather, they have complementary features that are related to the complementary roles the objects play in events or scenarios. Thematic relations play an important role in children's semantic

representations (e.g., Nguyen & Murphy, 2003; Waxman & Namy, 1997) and continue to do so into adulthood (e.g., Lin & Murphy, 2001; Murphy, 2001; Ross & Murphy, 1999; see also Goldwater, Markman, & Stilwell, 2010; for a review, see Estes et al., 2011) and may be even stronger for older adults (e.g., Maintenant, Blaye, & Paour, 2011; Smiley & Brown, 1979).

Most studies investigating thematic relations have used tasks that explicitly require assessing these relations or semantic relations more generally. For example, the "triads" task, in which participants are asked to choose which of two options is most related to a target, has been used extensively to study thematic thinking (e.g., Lin & Murphy, 2001). Fewer studies have examined whether thematic similarity is engaged during tasks that do not require it. McRae, Hare, and colleagues used a semantic priming paradigm to demonstrate that event-based relations are activated during simple visual word recognition (Ferretti, McRae, & Hatherell, 2001; Hare, Jones, Thomson, Kelly, & McRae, 2009; McRae, Hare, Elman, & Ferretti, 2005; Ross & Murphy, 1999; for a review, see Hutchison, 2003; for other evidence, see also Rahman & Melinger, 2007). In a large-scale study of picture naming errors produced by individuals with aphasia, Schwartz et al. (2011) showed that individuals differed in their tendency to produce taxonomic errors (coordinate, superordinate, or subordinate noun substitutions) versus thematic semantic errors (nontaxonomic errors that named an object that co-occurred with the target in the context of an action, event, or sentence). The behavioral results showed a single dissociation: There were far more taxonomic errors than thematic errors (approximately 5:1 ratio). However, a lesion analysis of tendencies to produce errors of one type controlling for the other revealed a neuroanatomical double dissociation. Lesions affecting the left anterior temporal lobe (ATL) caused a higher proportion of taxonomic errors, and lesions affect-

ing the left temporoparietal junction (TPJ) caused a higher proportion of thematic errors.

On the basis of these results, Schwartz et al. (2011) proposed that there may be complementary semantic systems: one system, with ATL as the critical hub, that captures taxonomic relations that are based on feature overlap, and a second system, with TPJ as the critical hub, that captures thematic relations based on complementary roles in events or scenarios. The ATL is already well-established as a critical hub for semantic processing, especially feature-based category relations (e.g., Hodges, Graham, & Patterson, 1995; Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001; Patterson, Nestor, & Rogers, 2007; Schwartz et al., 2009), and the TPJ has been established as a critical region for event-based and action-based relations (e.g., Kalénine et al., 2009; Wu, Waller, & Chatterjee, 2007; for a recent comprehensive review of neuroimaging studies of semantic representations, see Binder, Desai, Graves, & Conant, 2009). Crutch and Warrington (2005, 2010) have also proposed a related two-semantic-systems account to explain their findings that concrete concepts rely more strongly on feature-based taxonomic relations and abstract concepts rely more strongly on association-based relations.

If there are complementary semantic systems, then individuals may vary in the relative strength of these two systems. The Schwartz et al. (2011) data show that adults with aphasia vary in this way, but it is not known to what extent the two systems contribute independently across tasks for neurologically intact adults. The current study investigated this question in adults of the same age range as the aphasic participants in that study. Further, Schwartz et al. examined only picture naming, so their results could be due to effects of stroke either on core semantic processing or on lexical access processes. Simmons and Estes (2008) demonstrated a systematic correlation in typical adults' responses in two versions of the triads task (similarity and difference judgments), suggesting that there may be individual-specific preferences for taxonomic versus thematic relations. However, their results were limited to a task that explicitly requires weighting taxonomic and thematic semantic relations, and the individual differences could reflect differences in interpretation of the instructions (for triads task performance sensitivity to instructions see, e.g., Lin & Murphy, 2001). The current study was designed to test cross-task individual differences, which would localize the effects to those cognitive processes that the tasks have in common—namely, core semantic processing. Finding such cross-task individual differences would provide important converging evidence that taxonomic and thematic knowledge comprise complementary semantic systems.

In the present experiments we used eye tracking to provide a novel demonstration of activation of thematic knowledge during a task that does not require it (understanding a spoken word). We then showed that the relative degree of activation of taxonomically and thematically related concepts during word recognition predicts each individual's tendency to choose between taxonomic and thematic options in a triads task.

The Experiment

The first part of the experiment was designed to test whether taxonomically and thematically related concepts are both activated during single word processing, even when the task demands do not require it, and to measure the degree of activation of each kind of relation for each participant. To measure activation of related concepts during spoken word recognition we used the "visual world paradigm" (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). In the interactive version of the task, participants were shown four pictures and asked to click on the one that matched the spoken word; in the passive version of the task, participants were simply asked to look at the pictures while listening to the word. Previous studies using this paradigm have shown that participants are more likely to look at pictures of objects that are semantically related to the target than at unrelated objects (e.g., Huettig & Altmann, 2005; Mirman & Magnuson, 2009; Yee & Sedivy, 2006), though not at objects that are only related by virtue of their names co-occurring with no semantic relationship (e.g., *iceberg* and *lettuce*; Yee, Overton, & Thompson-Schill, 2009). The second part of the experiment used a standard triads task procedure to evaluate whether individual differences in the tendency to choose the taxonomically related option over a thematically related option is predicted by the relative activation of taxonomically related and thematically related concepts during spoken word recognition. These two tasks were chosen because they have quite different cognitive demands: One is a spoken word recognition task in which semantic relations are irrelevant and, if activated, distracting; the other is a nonverbal task that requires explicit evaluation of semantic relations. Cross-task individual differences in these tasks would be strong evidence that neurologically intact adults differ in their reliance on taxonomic versus thematic knowledge.

Method

Participants

Thirty adult participants (50% female; 83% Caucasian, 17% African American) completed the study. Their mean age was 66 (range = 42–77) and mean years of education was 15 (range = 12–21). Older adults were tested because we sought to evaluate whether the complementary semantic systems suggested by the Schwartz et al. (2011) study of adults with aphasia would hold for neurologically intact adults of a similar age. Older adults may rely on thematic knowledge more strongly than younger adults (Maintenant et al., 2011; Smiley & Brown, 1979), so age was included as a variable in our analyses.

All participants had English as their native language and had no major psychiatric or neurologic comorbidities. All participants scored in the normal range (M = 29, range = 26–30) on the Mini-Mental State Exam (Folstein, Folstein, & McHugh, 1975), confirming that they had no cognitive impairments. Participants were paid for their participation and reimbursed for travel and related expenses.

Materials

For the spoken word recognition portion, the critical stimuli consisted of 20 taxonomically related pairs and 20 thematically related pairs. For each critical related pair, two phonologically and semantically unrelated pictures were also selected to serve as unrelated distractors. An additional 30 sets of four unrelated

pictures were selected to serve as practice (10) and filler (20) trials. For the triads portion, the stimuli consisted of 20 triads of target picture, taxonomically related picture, and thematically related picture (there was also an additional set of five practice triads). The critical relations were assigned on the basis of the coding scheme used by Schwartz et al. (2011) to code picture naming errors: Taxonomically related pairs shared a semantic category, and thematically related pairs frequently participated in an event or scenario and were not members of the same category.

Picture stimuli were drawn from a normed set of 260 color drawings of common objects (Rossion & Pourtois, 2004). Due to this limited set of images, two related pairs from the word recognition portion were repeated during the triads portion, but none of the reported patterns were affected by excluding these two triads trials from analysis. Images had a maximum size of 200 × 200 pixels and were scaled such that at least one dimension was 200 pixels. (The full list of stimuli is in Appendix A; the Rossion and Pourtois images are available at http://stims.cnbc.cmu.edu/Image%20Databases/TarrLab/Objects/). Stimulus words for the word recognition portion were recorded by a native English speaker at 44.1 kHz. The individual words were edited to eliminate silence at the beginning and end of each sound file.

Target and competitor words were matched on word frequency, familiarity, length, and neighborhood density across the two conditions (all $p > .15$). A separate semantic relatedness norming study ($N = 15$, who did not participate in the main study but were drawn from the same population) was conducted to validate our stimulus selection. Each of the three critical pairings from the word recognition portion (target–competitor, target–unrelated 1, target–unrelated 2) and the two pairings from the triads portion (target–taxonomic option, target–thematic option) were presented for taxonomic and thematic relatedness rating in two separate sessions (at least 1 week apart; the order was counterbalanced across participants). Like the stimulus selection, the norming questions were based on the norming done by Schwartz et al. (2011). In the taxonomic rating session, participants were asked to "decide to what extent these two things are members of the same category"; in the thematic rating session, participants were asked to "decide to what extent these two things co-occur in a situation or scene." The results revealed that, as in Schwartz et al., our materials captured the taxonomic–thematic distinction somewhat asymmetrically. The average ratings on the thematic dimension were only slightly higher for thematic (4.4) than taxonomic (4.3) pairs, whereas ratings on the taxonomic dimension were substantially higher for taxonomic (4.1) than thematic (3.4) pairs (the interaction between pair type and rating type was highly significant both by items and by subjects; both $F > 10$, $p < .01$). Note that because our primary focus was on individual differences in the magnitude of taxonomic competition relative to thematic competition (i.e., activation of taxonomic relations controlling for activation of thematic relations), it is only critical that the two pair types show differential taxonomic and thematic relatedness (i.e., the interaction between pair type and rating type), not that their relatedness be limited to exactly one type. Unrelated items for the visual world paradigm portion received low relatedness ratings on both dimensions (taxonomic: 1.2; thematic: 1.3).

Apparatus

Participants were seated approximately 24 in. (60.96 cm) away from a 17-in. (43.18-cm) monitor with the resolution set to 1024 × 768 dpi. Stimuli were presented using E-Prime Professional (Version 2.0) experimental design software. Responses were recorded using a mouse. During the spoken word recognition part of the experiment, a remote Eyelink 1000 eye tracker was used to record participants' left eye gaze position at 250 Hz.

Procedure

During the word recognition part of the experiment, each trial began with a 1,300 ms preview of a four-image display in which each image was near one of the screen corners. Each display contained a target object image, a semantic competitor (taxonomically or thematically related), and two unrelated distractors. The position of the four pictures was randomized for each trial for each participant. During the last 300 ms of the preview, a red circle appeared in the center of the screen to draw attention back to the neutral central location. After the preview, participants heard the target word through speakers. There were a total of 70 trials: 10 practice trials (on which feedback was provided), 20 trials with taxonomic competitors, 20 trials with thematic competitors, and 20 filler trials where none of the images were related to each other. Trial order for the 60 nonpractice trials was randomized.

Half of the participants completed the interactive version of the task, in which participants were instructed to initiate each trial by clicking on a plus sign (+) in the center of the screen and then to click on the picture that corresponded to the spoken word. The other half completed the passive version, in which participants were simply instructed to look at the screen while listening to the spoken words. For the passive version, each trial began after a 1-s fixation screen and ended 4 s after word onset. This passive version of the task was added to test the activation of semantically related concepts when participants do not have to perform any task at all. Participants were told that their eye movements would be recorded, and the testing session began with a calibration, but they were not instructed to move their eyes in any particular way (aside from the passive task's general instruction to look at the screen). We expected that participants would look at the target object (at the very least, to guide their mouse movements in the interactive version of the task), but any looks to the semantically related competitors would reflect incidental activation of semantically related concepts.

During the triads part of the experiment, on each trial, participants were presented with a single picture near the bottom of the screen; once they clicked on that target image, the taxonomically related object and thematically related object images appeared near the top of the screen (assignment to left vs. right side was randomized). Participants were informed that both of the top pictures might be related to the bottom picture and to pick the one that "goes best" with the target object. We chose this somewhat thematically biased phrasing because adults generally have a taxonomic bias in this task and our focus on individual differences called for a more balanced response profile. The experiment began with five practice trials, which were followed by 20 critical trials in random order.
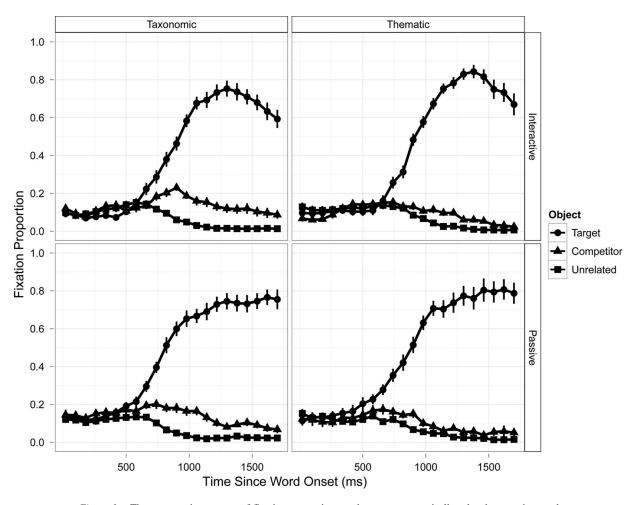
Results and Discussion

Eye Tracking Data

For the interactive version, accuracy was very high ($> 99\%$ correct in both conditions, $p > .3$) and mean response times were approximately 2,000 ms from word onset with no difference between conditions (taxonomic: $M = 2018$, $SD = 396$; thematic: $M = 1959$, $SD = 496$; $F < 1$, $p > .3$). Only correct response trials were included in the fixation analysis. Figure 1 shows the time course of fixations to the target, semantically related competitor, and unrelated distractors (average of the two unrelated distractors) from word onset. Participants were more likely to fixate semantically related competitors than unrelated distractors in both the taxonomically and thematically related conditions.

The competition analysis considered semantic competitor and unrelated distractor fixations from 500 ms after target word onset (shortly before the target fixations began to separate from the other conditions, indicating that fixations were starting to be driven by linguistic/semantic processing) to 1,700 ms after word onset (at which point competition had been mostly resolved and competitor

fixations were nearly at floor). To quantify the time course of the semantic competition effects we used growth curve analysis, a multilevel regression modeling technique using fourth-order orthogonal polynomials (Mirman et al., 2008). We focused specifically on the effect of object type (competitor vs. unrelated) on the intercept term, which captures the overall difference in fixation proportions for the semantic competitor compared to the unrelated distractor (full analysis results are provided in Appendix B). The results confirmed semantic competition in both the interactive and passive task versions for the taxonomic condition (interactive: estimate $= 0.086$, $SE = 0.009$, $p < .00001$; passive: estimate $= 0.083$, $SE = 0.011$, $p < .00001$) and the thematic condition (interactive: estimate $= 0.036$, $SE = 0.005$, $p < .00001$; passive: estimate $= 0.040$, $SE = 0.012$, $p < .001$). A similar analysis of the preview period data revealed no effects of object relatedness on any of the time terms (all $t < 1.5$, $p > .1$) in any of the four cases (2 relation types $\times$ 2 task versions); thus, the eye data indicate that participants did not begin to consider object relatedness before the onset of the target word. These results reveal that thematically and taxonomically related competitors were

Figure 1. The average time course of fixation proportions to the target, semantically related competitor, and unrelated distractor objects starting at target word onset. The top row shows data from the interactive task version, and the bottom row shows data from the passive task version. Error bars indicate $\pm$ 1 standard error.

both activated in the course of spoken word recognition, even when participants were merely asked to look at the screen while listening to the words. This new evidence further demonstrates that thematic relationships are an intrinsic part of the representations of word meanings and are activated even when the task demands do not require it.

As is clear in Figure 1, the taxonomic competition effect was substantially larger than the thematic competition effect. This difference needs to be interpreted with caution. First, the norms indicated that the taxonomic competitors were also thematically related, so they may simply be stronger semantic competitors. Second, taxonomically related concepts, by definition, are likely to share visual features, which would increase fixation probability even if the pictures themselves do not share the similarity (Dahan & Tanenhaus, 2005; Yee, Huffstetler, & Thompson-Schill, 2011). Choosing taxonomically related concepts that do not share visual features would mean selecting the atypical category members (e.g., mammals that do not look like mammals), which would produce skewed materials. Third, if thematic knowledge is more important for events or other multiobject relational processing and taxonomic knowledge is more important for identification of individual concrete objects (Schwartz et al., 2011; see also Crutch & Warrington, 2005, 2010), then it would be reasonable to expect recognition of single words that refer to concrete objects to be dominated by taxonomic knowledge.

Quantifying Individual Effect Sizes

To quantify how much taxonomic and thematic competitors were activated for each individual participant, we computed the difference between average fixation proportions for the competitor and unrelated distractors for each participant (analogous to differences on the intercept term). A relative effect size for each participant was computed by subtracting thematic competition effect size from taxonomic competition effect size. This produced a relative measure of how much bigger each individual's taxonomic competition effect was compared to the thematic competition effect—that is, each individual's tendency to activate taxonomic relations more strongly than thematic relations during spoken word recognition. This measure was then used to predict the tendency to choose the taxonomic option in the triads task in the second part of the experiment. This relative effect size measure did not differ on the basis of any of the demographic variables (gender, ethnicity, age, education, or Mini-Mental State Exam; all $p > .45$). One participant from the passive task version was excluded from the cross-task effect size analyses because this participant's eye movements did not appear to be driven by linguistic input.[1]

Triads Data

The overall mean number of taxonomic selections was 9.6 ($SD = 4.6$, range $= 2–19$) out of 20 total trials with an approximately normal distribution. About one third of participants were clustered near 50% taxonomic selections (between nine and 11 selections), and only seven showed statistically reliable biases toward thematic ($N = 5$) or taxonomic ($N = 2$) responses. Differences in number of taxonomic selections were not predicted by any of the demographic variables (all $p > .3$). In contrast, Figure 2 shows that there was a positive association between the number of

taxonomic selections in the triads task and individual participants' relative taxonomic competition effect size in the spoken word recognition task. Logistic regression confirmed a positive effect of relative taxonomic competition effect size on number of taxonomic selections (estimate $= 7.24$, $SE = 2.5$, $p < .01$) and no effect of task or interaction with task (both $p > .15$). This pattern was also confirmed by Pearson correlation ($r = .42$, $p < .05$).[2] In sum, participants who showed bigger taxonomic competition effects relative to their thematic competition effects were more likely to choose the taxonomic option in a triads task. Because the item pairs used in the two tasks were (largely) different, this cross-task relation suggests that individual participants differed in their general—rather than stimulus-specific or task-specific—tendency to activate thematic versus taxonomic relations.
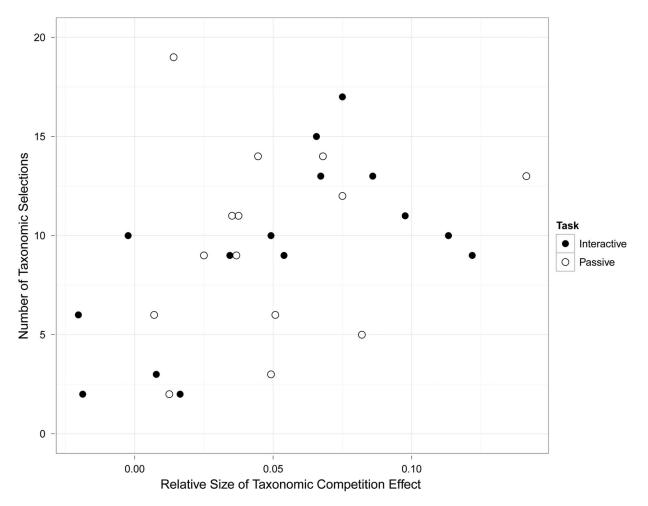
Conclusions

The present results provide new evidence that thematic relations are activated even when the task does not explicitly require it (spoken word comprehension) and showed that, across individuals, the relative activation of taxonomically related concepts compared to thematically related concepts predicted the tendency to choose the taxonomic option in a semantic similarity judgment task. These two tasks pose quite different cognitive demands: One is a spoken word recognition task in which semantic relations are irrelevant and distracting; the other requires explicit semantic similarity judgments but does not require linguistic processing. Our finding of cross-task individual differences in these tasks provides strong evidence that neurologically intact adults differ in their reliance on taxonomic versus thematic knowledge.

Although some past studies have suggested that relative reliance on thematic knowledge is affected by age and education, we found no evidence of this in our study: Neither the differences in relative activation of taxonomically related concepts nor the tendency to choose them in the similarity judgment task were associated with demographic variables such as age or education. This null result indicates that age and education cannot be the underlying causes of the individual differences demonstrated here and suggests that a broader range of age and education is required to show those effects. Past studies suggested that individuals vary in their preferences for taxonomic versus thematic relations in explicit similarity judgment tasks (Simmons & Estes, 2008), and our converging results indicate that these individual differences arise from intrinsic,

---

[1] This participant was the only one who was less than two times more likely to fixate the target object than nontarget objects. Since this participant's eye movements did not appear to reflect activation of the target word, we do not believe that they accurately reflect the degree of activation of the competitors. Excluding this participant from the fixation data analysis had no substantive impact on those results, so the more inclusive results were reported for the fixation analysis.

[2] Both the logistic regression and the correlation analysis results were unchanged by excluding the two trials that involved repeated item pairs. The logistic regression revealed an effect of relative taxonomic competition effect size on number of taxonomic selections (estimate $= 7.25$, $SE = 2.7$, $p < .01$) and no effect of task or interaction with task (both $p > .20$); the correlation analysis confirmed this result ($r = .41$, $p < .05$).

Figure 2. Association between relative taxonomic competition effect size and tendency to choose the taxonomic option in a triads task. Both the interactive (filled symbols) and passive (open symbols) task versions show the same pattern.

cross-task differences in activation of taxonomic and thematic relations. Combined with recent evidence that taxonomic and thematic knowledge are neuroanatomically distinct (Schwartz et al., 2011) and contribute differentially to processing of concrete and abstract concepts (Crutch & Warrington, 2005, 2010), the present data suggest that meaning information is organized in two parallel, complementary semantic systems.

References

Barsalou, L. W. (2010). Ad hoc categories. In P. C. Hogan (Ed.), *The Cambridge encyclopedia of the language sciences* (pp. 87–88). New York, NY: Cambridge University Press.

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex, 19,* 2767–2796. doi: 10.1093/cercor/bhp055

Collins, A. M., & Loftus, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review, 82,* 407–428. doi:10.1037/ 0033-295X.82.6.407

Cree, G. S., McRae, K., & McNorgan, C. (1999). An attractor model of lexical conceptual processing: Simulating semantic priming. *Cognitive Science, 23,* 371–414. doi:10.1207/s15516709cog2303_4

Crutch, S. J., & Warrington, E. K. (2005). Abstract and concrete concepts have structurally different representational frameworks. *Brain, 128,* 615–627. doi:10.1093/brain/awh349

Crutch, S. J., & Warrington, E. K. (2010). The differential dependence of abstract and concrete words upon associative and similarity-based information: Complementary semantic interference and facilitation effects. *Cognitive Neuropsychology, 27*(1), 46–71. doi:10.1080/ 02643294.2010.491359

Dahan, D., & Tanenhaus, M. K. (2005). Looking at the rope when looking for the snake: Conceptually mediated eye movements during spoken-word recognition. *Psychonomic Bulletin & Review, 12,* 453–459. doi: 10.3758/BF03193787

Estes, Z., Golonka, S., & Jones, L. L. (2011). Thematic thinking: The apprehension and consequences of thematic relations. *Psychology of Learning and Motivation, 54,* 249–294. doi:10.1016/B978-0-12-385527-5.00008-5

Ferretti, T. R., McRae, K., & Hatherell, A. (2001). Integrating verbs, situation schemas, and thematic role concepts. *Journal of Memory and Language, 44,* 516–547. doi:10.1006/jmla.2000.2728

Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental

State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research, 12,* 189–198. doi: 10.1016/0022-3956(75)90026-6

Goldwater, M. B., Markman, A. B., & Stilwell, C. H. (2010). The empirical case for role-governed categories. *Cognition, 118,* 359–376. doi: 10.1016/j.cognition.2010.10.009

Hare, M., Jones, M., Thomson, C., Kelly, S., & McRae, K. (2009). Activating event knowledge. *Cognition, 111,* 151–167. doi:10.1016/j.cognition.2009.01.009

Hodges, J. R., Graham, N., & Patterson, K. (1995). Charting the progression in semantic dementia: Implications for the organisation of semantic memory. *Memory, 3,* 463–495. doi:10.1080/09658219508253161

Huettig, F., & Altmann, G. T. M. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual world paradigm. *Cognition, 96,* B23–B32. doi:10.1016/j.cognition.2004.10.003

Hutchison, K. A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin & Review, 10,* 785–813. doi:10.3758/BF03196544

Kalénine, S. N., Peyrin, C., Pichat, C. D., Segebarth, C., Bonthoux, F. O., & Baciu, M. (2009). The sensory-motor specificity of taxonomic and thematic conceptual relations: A behavioral and fMRI study. *NeuroImage, 44,* 1152–1162. doi:10.1016/j.neuroimage.2008.09.043

Lambon Ralph, M. A., McClelland, J. L., Patterson, K., Galton, C. J., & Hodges, J. R. (2001). No right to speak? The relationship between object naming and semantic impairment: Neuropsychological evidence and a computational model. *Journal of Cognitive Neuroscience, 13,* 341–356. doi:10.1162/08989290151137395

Lin, E. L., & Murphy, G. L. (2001). Thematic relations in adults' concepts. *Journal of Experimental Psychology: General, 130,* 3–28. doi:10.1037/0096-3445.130.1.3

Maintenant, C., Blaye, A., & Paour, J.-L. (2011). Semantic categorical flexibility and aging: Effect of semantic relations on maintenance and switching. *Psychology and Aging, 26,* 461–466. doi:10.1037/a0021686

Markman, E. M. (1991). *Categorization and naming in children: Problems of induction.* Cambridge, MA: MIT Press.

McRae, K., Hare, M., Elman, J. L., & Ferretti, T. (2005). A basis for generating expectancies for verbs from nouns. *Memory & Cognition, 33,* 1174–1184. doi:10.3758/BF03193221

Mervis, C. B., & Rosch, E. (1981). Categorization of natural objects. *Annual Review of Psychology, 32,* 89–115. doi:10.1146/annurev.ps.32.020181.000513

Mirman, D., Dixon, J. A., & Magnuson, J. S. (2008). Statistical and computational models of the visual world paradigm: Growth curves and individual differences. *Journal of Memory and Language, 59,* 475–494. doi:10.1016/j.jml.2007.11.006

Mirman, D., & Magnuson, J. S. (2009). Dynamics of activation of semantically similar concepts during spoken word recognition. *Memory & Cognition, 37,* 1026–1039. doi:10.3758/MC.37.7.1026

Murphy, G. L. (2001). Causes of taxonomic sorting by adults: A test of the thematic-to-taxonomic shift. *Psychonomic Bulletin & Review, 8,* 834–839. doi:10.3758/BF03196225

Nguyen, S. P., & Murphy, G. L. (2003). An apple is more than just a fruit: Cross-classification in children's concepts. *Child Development, 74,* 1783–1806. doi:10.1046/j.1467-8624.2003.00638.x

O'Connor, C. M., Cree, G. S., & McRae, K. (2009). Conceptual hierarchies in a flat attractor network: Dynamics of learning and computations. *Cognitive Science, 33,* 1–19.

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience, 8,* 976–987. doi:10.1038/nrn2277

Rahman, R. A., & Melinger, A. (2007). When bees hamper the production of honey: Lexical interference from associates in speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33,* 604–614. doi:10.1037/0278-7393.33.3.604

Rogers, T. T., & McClelland, J. L. (2004). *Semantic cognition: A parallel distributed processing approach.* Cambridge, MA: MIT Press.

Ross, B. H., & Murphy, G. L. (1999). Food for thought: Cross-classification and category organization in a complex real-world domain. *Cognitive Psychology, 38,* 495–553. doi:10.1006/cogp.1998.0712

Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, 33,* 217–236. doi:10.1068/p5117

Schwartz, M. F., Kimberg, D. Y., Walker, G. M., Brecher, A., Faseyitan, O., Dell, G. S., . . . Coslett, H. B. (2011). A neuroanatomical dissociation for taxonomic and thematic knowledge in the human brain. *Proceedings of the National Academy of Sciences, USA, 108,* 8520–8524. doi:10.1073/pnas.1014935108

Schwartz, M. F., Kimberg, D. Y., Walker, G. M., Faseyitan, O., Brecher, A., Dell, G. S., & Coslett, H. B. (2009). Anterior temporal involvement in semantic word retrieval: Voxel-based lesion-symptom mapping evidence from aphasia. *Brain, 132,* 3411–3427. doi:10.1093/brain/awp284

Simmons, S., & Estes, Z. (2008). Individual differences in the perception of similarity and difference. *Cognition, 108,* 781–795. doi:10.1016/j.cognition.2008.07.003

Smiley, S. S., & Brown, A. L. (1979). Conceptual preference for thematic or taxonomic relations: A nonmonotonic age trend from preschool to old age. *Journal of Experimental Child Psychology, 28,* 249–257. doi:10.1016/0022-0965(79)90087-0

Smith, E. E., Shoben, E. J., & Rips, L. J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81,* 214–241. doi:10.1037/h0036351

Tanenhaus, M. K., Spivey-Knowlton, M. J., Eberhard, K. M., & Sedivy, J. C. (1995). Integration of visual and linguistic information in spoken language comprehension. *Science, 268,* 1632–1634. doi:10.1126/science.7777863

Waxman, S. R., & Namy, L. L. (1997). Challenging the notion of a thematic preference in young children. *Developmental Psychology, 33,* 555–567. doi:10.1037/0012-1649.33.3.555

Wu, D. H., Waller, S., & Chatterjee, A. (2007). The functional neuroanatomy of thematic role and locative relational knowledge. *Journal of Cognitive Neuroscience, 19,* 1542–1555. doi:10.1162/jocn.2007.19.9.1542

Yee, E., Huffstetler, S., & Thompson-Schill, S. L. (2011). Function follows form: Activation of shape and function features during word recognition. *Journal of Experimental Psychology: General, 140,* 348–363. doi:10.1037/a0022840

Yee, E., Overton, E., & Thompson-Schill, S. L. (2009). Looking for meaning: Eye movements are sensitive to overlapping semantic features, not association. *Psychonomic Bulletin & Review, 16,* 869–874. doi:10.3758/PBR.16.5.869

Yee, E., & Sedivy, J. C. (2006). Eye movements to pictures reveal transient semantic activation during spoken word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 1–14. doi:10.1037/0278-7393.32.1.1

(Appendices follow)

Appendix A

Experiment Stimuli

Table A1

Stimuli for the Spoken Word Recognition (Visual World Paradigm) Portion

Condition	Target	Competitor	Unrelated 1	Unrelated 2
Thematic	anchor	sailboat	French horn	grasshopper
Thematic	ashtray	cigarette	rhino	lettuce
Thematic	balloon	clown	rolling pin	donkey
Thematic	barn[a]	pig	jello	ironing board
Thematic	bird	tree[a]	honey	guitar
Thematic	eye	glasses	seal	chisel
Thematic	football	helmet (football)	beetle	harp
Thematic	hair	comb	drum	corn
Thematic	hammer	nail	chicken	flag
Thematic	hand	glove	leaf	mushroom
Thematic	hanger[a]	blouse	cherry	doll
Thematic	kettle	stove[a]	cat	door
Thematic	lamp	table	box	chain
Thematic	lock	key	pear	belt
Thematic	monkey	banana	bicycle	house
Thematic	needle	thread	piano	caterpillar
Thematic	sheep	sweater	light switch	frying pan
Thematic	sock	foot[a]	seahorse	cake
Thematic	toaster	bread	snowman	baby carriage
Thematic	vase	flower[a]	sled	bow
Taxonomic	airplane[a]	helicopter[a]	swan	well
Taxonomic	ant	spider	asparagus	book
Taxonomic	bat	racket	celery	dresser
Taxonomic	bus	train	peacock	refrigerator
Taxonomic	cigar	pipe	fish	garbage can[a]
Taxonomic	cup	glass[a]	iron	kangaroo
Taxonomic	deer	cow	light bulb	coat
Taxonomic	ear	nose[a]	accordion	windmill
Taxonomic	fork	knife	ostrich	purse
Taxonomic	gun	cannon	spinning wheel	artichoke
Taxonomic	leg	arm	strawberry	turtle
Taxonomic	moon	sun	envelope	doorknob
Taxonomic	motorcycle[a]	car	umbrella	tomato
Taxonomic	necklace	ring[a]	plug	saltshaker
Taxonomic	owl	eagle	ladder	nail file
Taxonomic	paintbrush	pen	mountain	onion
Taxonomic	top	ball	ruler	skunk
Taxonomic	violin	flute	potato	clothespin
Taxonomic	watch	clock	grapes	heart
Taxonomic	wrench[a]	pliers[a]	roller skate	rooster

[a] Image later appeared in Triads portion (9.4% of Visual World Paradigm images).

Table A2
Stimuli for Triads Portion

Target	Thematic option	Taxonomic option
finger	ring[a]	thumb
bell	church	whistle
pants	button	skirt
raccoon	garbage[a]	squirrel
axe	tree[a]	scissors
boot	foot[a]	shoe
mouth	toothbrush	nose[a]
couch	television	bed
carrot	rabbit	pepper
horse	barn[a]	dog
shirt	hanger[a]	dress
chair	desk	stool
helmet (motorcycle)	motorcycle[a]	cap
elephant	peanut	giraffe
wrench[b]	nut	pliers[b]
airplane[b]	cloud	helicopter[b]
apple	basket	orange
pot	stove[a]	bowl
bee	flower[a]	fly
bottle	barrel	glass[a]

[a] Image previously appeared in spoken word recognition portion (25% of triads images).   [b] Image pair previously appeared in spoken word recognition portion (5% of triads pairs).

Appendix B

Table B1
Growth Curve Analysis Results for Semantic Competition in the Two Conditions for Each Task

Model term	Task	Taxonomic			Thematic		
		Est. (*SE*)	*t*	*p<*	Est. (*SE*)	*t*	*p<*
Intercept	Interactive	0.086 (0.009)	9.3	0.00001	0.036 (0.005)	6.8	0.00001
	Passive	0.083 (0.011)	7.3	0.00001	0.040 (0.012)	3.3	0.001
Linear	Interactive	0.150 (0.062)	2.4	0.05	0.037 (0.045)	0.8	*ns*
	Passive	−0.034 (0.048)	0.9	*ns*	−0.022 (0.047)	0.5	*ns*
Quadratic	Interactive	−0.240 (0.032)	7.5	0.00001	−0.084 (0.042)	2.0	0.05
	Passive	−0.150 (0.032)	4.7	0.00001	−0.011 (0.034)	0.3	*ns*
Cubic	Interactive	0.086 (0.014)	6.3	0.00001	−0.030 (0.013)	2.2	0.05
	Passive	0.093 (0.013)	7.2	0.00001	0.053 (0.012)	4.5	0.00001
Quartic	Interactive	0.041 (0.014)	3.0	0.01	0.033 (0.013)	2.4	0.05
	Passive	0.006 (0.013)	0.5	*ns*	−0.012 (0.012)	1.0	*ns*

Note. Parameter estimates are for the semantically related competitor relative to the unrelated distractor. Est = estimate.