Relational Words as Handles: They Bring Along Baggage

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Abstract

Two experiments examined the role of relational language on analogical transfer. Participants were taught Signal Detection Theory (SDT) embedded in a doctor story and in the experimental condition relational words accompanied the story. Relational words that shared superficial similarity with the contextual elements facilitated transfer. Without the shared semantics, relational words were detrimental to transfer performance. A computational model lends a more structured perspective on how language changes cognition.

Introduction

Most people simply expect learning words to lead to learning concepts because we use language to communicate ideas. Evidence of this intuition is found in the emphasis on vocabulary and "bolded words" in educational settings. Lexical categorization is considered equivalent to possessing certain concepts. Indeed, language has played a significant role in the development of human thought not only as a means of communication but also as a tool that augments our computational abilities (Clark, 1998; Gentner, 2003).

Language dovetails with other cognitive functions well because it can act as a filter for complex perceptual experience by directing our attention to particular similarities. An example of this filtering act is found in young children's shape bias where exposure to an object in the context of a noun shifts attention to shape (Landau, Smith, & Jones, 1988). In some cases, words can even overshadow perceptual experiences (Schooler, 2002).

Relational language is a particularly powerful illustration of these qualities of language since relations are not as perceptually salient or stable as objects (Gentner, 2003). Four-year-olds show sensitivity to higher-order similarity relations such as symmetry after being exposed to triads like xXx that were labeled "even" (Kotovsky & Gentner, 1995). Even when the relational answer was not perceptually salient (e.g. matching color symmetry to size symmetry), these children were able to make relational choices. Consistent use of the word "even" gave rise to a stable perception of similarity. The stability that relational language provides across contexts allows us to create equivalence classes that are otherwise difficult to pick out.

As helpful as language might be, relational words are notoriously difficult for children to learn (Keil & Batterman, 1984; Hall & Waxman, 1993). One reason for this difficulty can be found in Linda Smith's developmental account of similarity (1989) as shifting from global identity to part similarity to relational similarity. Relations are often learned in a rich context so the most conservative similarity (identity) might at first be the only way to preserve the abstraction. Linguistic labels can shift attention to other types of similarity and relational similarity requires the largest shifts.

How do words get this power to highlight relations? An experiment reported by Ratterman and Gentner (1998) showed that brief training with words children spontaneously use to mark monotonic change (*Daddy, Mommy,* and *Baby*) significantly increased relational responding over "no word control" children. However, this benefit of language was not found with arbitrary labels (*jiggy, gimli, fantan*). This result indicates that associations between relational words and other experiences significantly influences how words can highlight relations.

This relational benefit from words has often focused on language's provision of symbol-like handles for rich experiences (Clark, 1998; Gentner, 2003). Words are relatively unperturbed by idiosyncratic differences in context (i.e. tokens of the word *dog* said at different times are perceived as highly similar). This perceptual stability also makes words seem object-like. Labels are arbitrary in the sense that words are non-iconic to their referents. Because of these qualities, language can act as an attention-shifter. Being relatively context-free and non-iconic allows language to represent or point out the non-obvious. Object-like words can make relations seem more concrete. However, theories about the mechanism of language (e.g. Elman, 1995) suggest that language has the appearance of being symbolic and context-free even though the underlying mechanism may be dynamic, continuous, and sensitive to context in real-time (for more about this claim see Clark, 1998, Dennett, 1991). The fact that *jiggy* doesn't work well as a relational label may be a consequence of the dual function of words to dramatically compress information and represent rich associative connections to other words and experiences. *Jiggy* lacks the rich associative connections for a child that *Mommy* possesses, despite its providing an efficient symbolic handle.

This paper examines this dual role of language in relational reasoning. Most of the experiments reviewed here illustrate difficulties that toddlers have with relational similarity, but even for adult learners, abstract relations are difficult to extract from a novel context (e.g. Goldstone & Sakamoto, 2003). Our hypothesis was that certain words might promote relational thinking. In the following between-subject experiments, there are two conditions: the word condition with relational labels included in the cover story, and the control condition without labels. The behavior of interest was the ability of learners to transfer what they learned from the learning situation to a new context. The underlying system of relations that participants learned and transferred was Signal Detection Theory (SDT).

The relational words that we used were: *target, distracter, hit, miss, correct rejection, false alarm.* We did not use the traditional SDT terms *signal* and *noise* because those are grounded in particular examples of SDT that are probably not familiar to our participants. Since *target* (especially in comparison to *distracter*) is a positive term, Experiment 1 paired it with a positive element in the cover story (*healthy athletes*) while *distracter* was paired with the corresponding negative element (*unhealthy athletes*). The relational labels were semantically aligned with the relations embedded in the context. Experiment 2 goes on to ask whether the semantic alignment is redundant and symbolic function of words is enough to produce transfer.

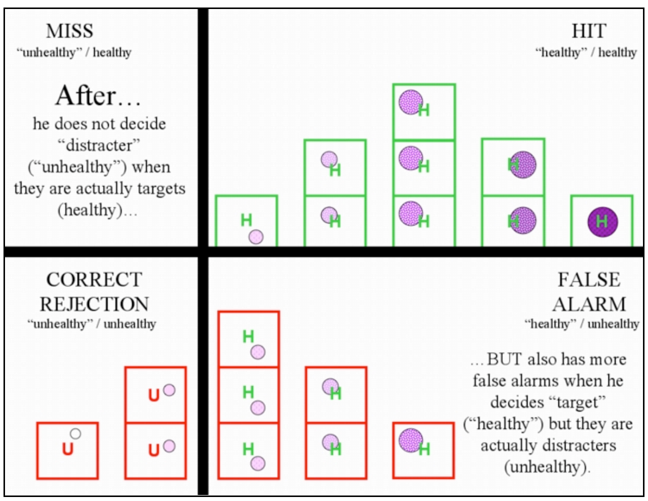

Figure 1: Screenshot from the word condition that have both relational (*target*) and contextual words (*healthy*). The control condition only had contextual words.

Experiment 1

Method

Eighty-seven undergraduates from Indiana University participated in this experiment for credit. Half were randomly assigned to be in the word condition and half were assigned to the control condition.

All undergraduates read through a computer-based SDT tutorial made up of pictures and explanatory text (a screenshot of the tutorial is shown in Figure 1). The principles of SDT are embedded in the context of a doctor trying to pick out healthy athletes to play for the university by examining blood cell strength. In the story, athletes with strong cell samples were more likely to be healthy than those with weak cell samples. Although cell strength was an imperfect indicator of health, the doctor tried to optimize his decisions. Within this cover story, the word condition also had relational labels for elements of the story. Healthy athletes were labeled *target* and the unhealthy athletes were *distracters*. Those that the doctor deemed "healthy" were labeled *"target"* with the quotation marks around both the contextual term and the relational term indicating that this is only the doctor's decision rather than the actual status of the athlete. Cell strength was labeled as *evidence. Hit, miss, correct rejection,* and *false alarm* were also included in the word condition's tutorial. Other than the addition of the labels, the tutorials for the word and control conditions were identical.

After reading through the tutorial at their own pace, participants answered eight multiple choice questions about the tutorial's doctor situation that could be answered correctly by applying SDT principles. All quiz questions were purposefully made difficult to ensure that they had to use SDT rather than relying on common sense. Participants had an opportunity to transfer what they had just learned to a different context because immediately following the tutorial quiz, they read a few paragraphs describing a small town that wants to export sweet melons and avoid sending out bitter melons. Sweet melons, laden with nectar, tend to be heavier so this town decides to sort the melons by weight (even though weight is not perfectly correlated with sweetness). Consumer reports allow them to find out which melons are actually sweet/bitter. An eight-question transfer quiz was administered. At the end of the experiment participants are told that these two stories are analogous and asked to explicitly map elements of the two stories to each other in a multiple choice quiz.

Results and Discussion

The relationship between the quizzes and the experimental manipulation were analyzed with a mixed-design 2x2 ANOVA (quiz type x word/no-word). There were no main effects for quiz type, $F(1, 85)=.040$, nor word manipulation, $F(1, 85)=.077$, but this analysis confirmed that there was a significant interaction, $F(1, 85)=8.627$, $p<.01$.

Separate analyses carried out on the quizzes revealed that the relational words made initial learning more difficult but produced a significant benefit for transfer to a new situation. Figure 2 illustrates a tendency for the control condition to do better, relative to the word condition, on the tutorial quiz for the initial learning situation, but this difference was only marginally significant, $t(86) = 3.032$, $p<.1$.

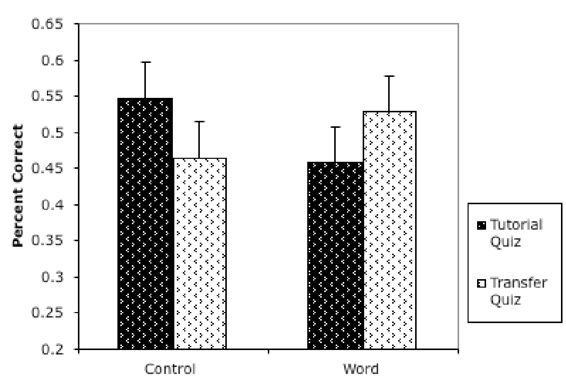

Figure 2: The interaction from Experiment 1.

An ANCOVA on transfer scores revealed that when the tutorial quiz score is considered as a significant covariate, $F(1, 84)=32.172$, $p<.001$, the word manipulation is a significant factor of transfer performance, $F(1, 84)=5.617$, $p<.05$. Overall the tutorial score influenced transfer score but even when the word participants did not do as well on the tutorial quiz, they were able to transfer more of what they learned. There were no differences in performance on the mapping quiz, $t(86)=.470$, with control and word participants scoring well, 85.5% and 82.4%, respectively.

The control participants who did well on the tutorial did not transfer their learning to the new situation. Part of the difficulty for those in the word condition may have been that the relational words were not used in the quiz questions rendering their hard-to-master words less useful in the task. The word participants who did not seem to learn as much in the tutorial were able to improve their performance in the transfer quiz. This interaction underscores the importance of separating variables that affect immediate learning versus those that make knowledge readily transferable (Goldstone & Sakamoto, 2003; Chi, Feltovich, & Glaser, 1981). The slight disadvantage of words in the tutorial quiz supports the notion that relational words are difficult to learn, not only for children (Keil & Batterman, 1984; Hall & Waxman, 1993) but also for adults. The success of the word condition on transfer could be interpreted as evidence for words making relations more salient, thereby allowing the two situations to seem more similar.

The labels used in this experiment had little in common with the contextualized item but most of the commonality was relational. Exposure to words might basically encourage transfer by directing attention to these few relational properties. However, the benefit of words might not exist if other non-relational aspects of the words seemed to run contrary to the context. To illustrate this point, since Ratterman and Gentner (1998) found that *Daddy-Mommy-Baby* were good terms for children to map according to monotonic decrease, then perhaps relational responding would be hampered if they labeled the small object *Daddy* and large object was called *Baby*. Even though words seem like powerful symbols, even when they are used systematically (i.e. preserving the monotonic changes of size), they may not be completely free of associations. Experiment 2 examined the consequences of labels that do not semantically correspond to the context.

Experiment 2

Method

Forty undergraduates were randomly assigned in a similar paradigm of learning SDT as Experiment 1. The main departure from Experiment 1 was a change in the tutorial's cover story. In the new story the doctor is trying to diagnose leukemia patients by examining blood samples. People with distorted cell samples are more likely to have leukemia than those with pure cell samples. Although cell distortion is an imperfect indicator of leukemia, the doctor must try to optimize his decisions.

The relational labels are the same as Experiment 1 only applied to the elements of the new story. The *targets* are now sick people and the *distracters* are healthy people. Those that the doctor has diagnosed are marked as "sick" and in the word condition they are accompanied by the label *"target."* Those that have been diagnosed as "healthy" are labeled *"distracters."* The tutorial quiz questions were reworded to reflect the changes in the story. The melon transfer story and quiz were identical to Experiment 1. Note that the relational words preserve the structure of SDT and are correctly applied to the doctor context. However we will refer to Experiment 2's manipulation as the inconsistent word condition to indicate that these words are semantically inconsistent with the story.

The elements included in the mapping quiz were accordingly adjusted but the questions remained structurally the same. However, the grading of this quiz was different because there are two viable answers for each mapping question. For example, for a mapping question such as, "What in the melon export story is most analogous to the sick patient in the doctor scenario?" students could pick the other target-like element (sweet melon), but answering bitter melon still preserves the structure of SDT since signal and noise are mathematically equivalent. In fact, in an impoverished setting like multiple choice, matching sick patients with bitter melons is more appealing than matching sick patients with sweet melons based on semantic overlap. Since the experimenters were familiar with SDT, the tutorial and transfer situations were designed with the sick person-sweet melon match (the signal/target match) in mind. One

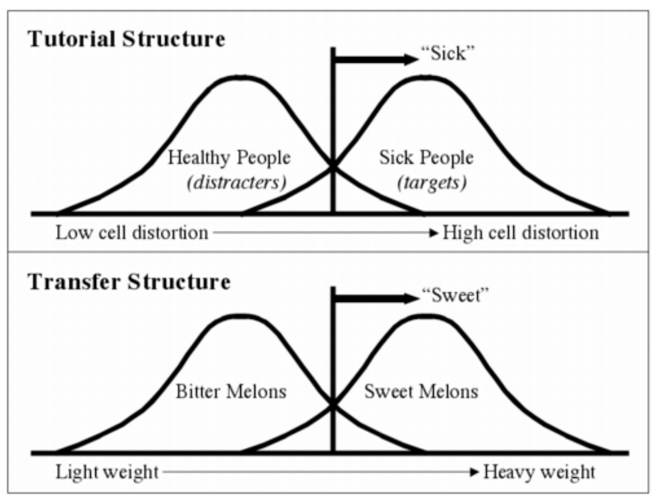

Figure 3: This shows the underlying structure of the SDT cover stories used in Experiment 2. Note that participants never saw this figure.

reflection of that intention is found in the spatial organization with cell distortion and melon weight increasing from left to right (for a schematic illustration see Figure 3). Thus the sick patients and sweet melons were usually presented on the right side of the computer screen. We will call this the structural answer. The mapping quiz was graded in three ways: a structural score, a semantic score, and a total mapping score (both answers counted as correct).

Results and Discussion

When the words were inconsistent with the story elements, the word condition did not experience the benefits normally associated with relational language. In both the tutorial and transfer quizzes, the control condition was superior to the word condition (shown in Figure 4). The tutorial quiz analysis revealed a trend that favored the control group although this difference was only marginally significant, $t(39)=2.83$, $p<.1$. However control participants outperformed those given inconsistent relational words on transfer, $t(39)=5.98$, $p<.05$. There was no reliable interaction between test type and word conditions according to a mixed-design ANOVA, $F(1, 38)=.991$. However there were significant main effects. Participants had significantly higher scores on the tutorial quiz, 53.8% (SD=.240), than the transfer quiz, 41.6% (SD=.266), $F(1, 38)=12.462$, $p<.001$. This should be expected considering that they just had a tutorial for the first quiz and only minimal background information for the transfer quiz. This analysis also confirmed that the control condition had better quiz scores than the word condition, $F(1, 38)=5.391$, $p<.05$. This transfer result counters the speculation that relational overlap between the label and the contextual referent generically leads to the correct abstraction.

Total mapping scores were not significantly different with the control group at 85.8% and the word condition scoring 80.0%, $t(39)=1.064$. The separated scores, shown as structural and semantic types of mapping in Figure 5, were analyzed with a mixed-design ANOVA. There was a main effect of mapping type with participants preferring to map by semantics, 50.42% (SD=.288), than pure structure, 32.5% (SD=.297), $F(1, 38)=4.405$, $p<.05$. There was no main effect of word condition, $F(1, 38)=1.064$, but there was a marginally significant interaction between these variables, $F(1, 38)=3.624$, $p<.07$.

Closer examination revealed that the control condition made significantly more semantic choices than the word condition, $t(39)=4.84$, $p<.05$. The semantic mapping result supports the notion that superficial similarity strongly influences mapping (Gentner & Toupin, 1986) but these mappings may or may not have been used in transfer (Ross, 1987). Since the structural choice is unintuitive, the poorly performing word condition did not show a significant tendency to make structural over semantic choices, $t(38)=2.070$. These mapping results imply that the word condition is confused. Instead of a consistently aligned view of the analogy, they seem to switch back and forth between structural and semantic construals. Words may cause some pull towards a structural perspective but cannot completely overcome the attractive semantic account. There is enough uncertainty to prevent word participants from settling on one coherent perspective. This instability may have contributed to their dismal results on transfer.

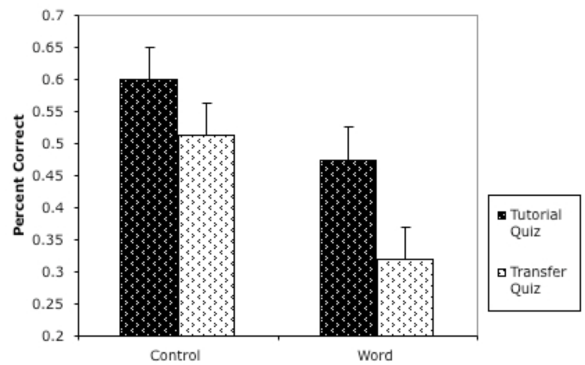

Figure 4: Tutorial and transfer quiz results of Experiment 2.

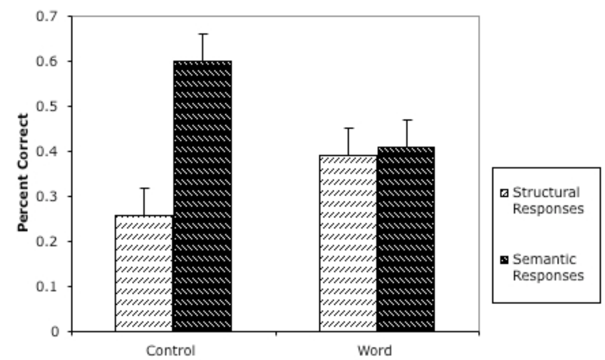

Figure 5: The mapping results from Experiment 2.

General Discussion

Taken in tandem, these relational word experiments reveal a system of effects that connect to important themes of research in analogical reasoning. There is much to find out about this remarkable ability to use abstract commonalities to solve superficially dissimilar problems, often the very goal of learning. These experiments explored how learning and applying deep principles (such as SDT) is sensitive to interactions between similarity, contextualization, and language.

Similarity is a major player in analogical mapping and usually object similarity is the least effortful mapping (Gentner & Toupin, 1986). Mapping with semantic or structural similarity is confounded in Experiment 1 but when they are in conflict as in Experiment 2, participants were more likely to map according to semantic similarity. However the perception of similarity is affected by language. When relational words are included, there is a shift in perspective and the highly intuitive semantic match becomes less attractive. However, since mapping was done at the end of the task, the participants may not have used these correspondences in the transfer task.

Understanding abstract concepts is a daunting task but inlayed in familiar and concrete contexts, those abstractions are more intelligible (Wason & Shapiro, 1971; Goldstone & Sakamoto, 2003). In both Experiments 1 and 2, the control group learned the abstractions *completely* embedded in the doctor context whereas the experimental participants also had exposure to decontextualized descriptors. Since the tutorial questions were also embedded in the doctor story, control participants did better. But sometimes a highly contextualized construal of a learning situation results in restricted transfer (Goldstone & Sakamoto, 2003; Anderson, Reder, & Simon, 1996). The control participants may have relied more heavily on the context that scaffolded performance on the tutorial quiz thus showing no improvement in transfer because that contextual support was no longer present. Relating context to language, Experiment 1 showed that the payoff for the difficult task of learning decontextualized relational words was found later in transfer performance.

Experiment 2 found a significant decline from scores on the tutorial to the transfer task. But there was no overall decrease from tutorial to transfer in Experiment 1. However, most of the decline in Experiment 2 is due to the poor performance of the word condition on transfer. These inconsistent words did not necessarily make the tutorial harder to understand for Experiment 2 because word conditions in both experiments had similar differences on the tutorial quiz compared to their respective control conditions. However, this result did not doom Experiment 1's word participants to worse transfer performance. Also note that in making the relational labels more dissimilar to the corresponding contextual item (*target-sick patient*), we did not experimentally change the similarity between the label and the corresponding element in the transfer story (*target-sweet melon*). Even so, the semantic inconsistencies between the relational labels and the learning situation were powerful enough to cause poor transfer in Experiment 2.

The benefit of relational words on transfer between semantically aligned contexts fits with other research on words and conceptual transfer (Kotovsky & Gentner, 1996; Ratterman & Gentner, 1998). Relational concepts made more object-like through words are easier to pick out of the surrounding context. However, the detrimental effect of superficially conflicting words on transfer reveals that the symbolic qualities of language alone are not enough to promote usable abstractions. In fact, it is the combination of grounded associations (Moyer & Bayer, 1976) *and* neat symbol-like qualities of words that allow language to act as a bridge across situations. The words that were slightly abstracted from the story yet shared some superficial similarities served as guides to deeper principles. However words that had conflicting superficial features could not achieve the same result.

As in many cases of learning, abstractions here were learned in situ with no immediate need for decontextualization. We propose that words facilitate abstraction by separating the relations from the features of context. This differentiation allows relational similarities to be selectively highlighted. For example, the features that were lumped into the concept of "healthy patient" could be split apart into "healthy patient" and "target" when presented with the relational word. Now the relations represented by "target" could have a larger influence on how the context is perceived.

However, the label "target" means lots of things including "goal (SDT signal)" and "good thing" and even though the label was used with only the former in mind, the latter comes along for the ride. If the contextual item also shares these meanings, the label acts as an abstraction that supports the story. On the other hand, if the relational label has conflicting features with the contextual item there are two ways of construing the original context: a relational version that contradicts the semantics of the story and a semantically aligned construal that goes against some of the relations.

A Potential Model

A model of the role of language in cognition would need to account for the symbol-like and association-driven qualities of human language use. Hybrid models that implement connectionist networks as well as a system of symbols are a good place to begin exploratory models of the cognitive consequences of language (Hutchins & Hazelhurst, 1991; Hummel & Holyoak, 1997). Since LISA (Learning and Inference with Schemas and Analogies, Hummel & Holyoak, 1997) is conveniently designed to simulate mapping between analogs and we have mapping results from these experiments, we will use it to illustrate how language might facilitate analogical mapping.

LISA was originally intended to be a model of analogical reasoning though analog retrieval and mapping (see Hummel & Holyoak, 1997 for a thorough treatment) with no explicit claims about the role of language in analogy. However, the architecture is a good illustration of the more qualitative theory proposed here concerning the interaction between the amodal symbol-like qualities and the context-sensitive flexibility of language.

LISA implements a hierarchical architecture built upon a constraint-satisfaction network (Holyoak & Hummel, 1997). The underlying web of associations in this network makes the hierarchical structures sensitive to semantic associations while being able to represent static structure. Dynamic synchrony in LISA allows the underlying associationist network to influence which symbolic structures become active. Co-activation leads to mapping. This duality of static structure and dynamic binding reflects the stability and flexibility of relational language found in the results reported here.

Consider a situation where all of the features of sick patient from the story are bound to the object *sick patient* and all features of healthy patients bound to *healthy patient* (see Figure 6a). When *sweet melon* gets active a portion of the relations in the associative layer (such as *looked for*, *goal*) are shared with *sick patient* but more object features are shared with *healthy patient*. This leads to co-activation and mapping between *sweet melon* and *healthy patient.*

The introduction of relational words changes this situation. If the sick patient semantics were split between *sick patient* and *target* shown in Figure 6b, LISA represents that *sick patient* is a *target* by learning to dynamically bind them together. Then when *sweet melon* becomes active, despite sharing some of the *healthy patient* semantics, almost all the *target* semantics become active. Since *target* is dynamically bound to *sick patient*, there is co-activation between *target, sick patient,* and *sweet melon.* The semantic match, *healthy patient*, is no longer the obvious mapping. The relational word allows the structural match to become a contender.

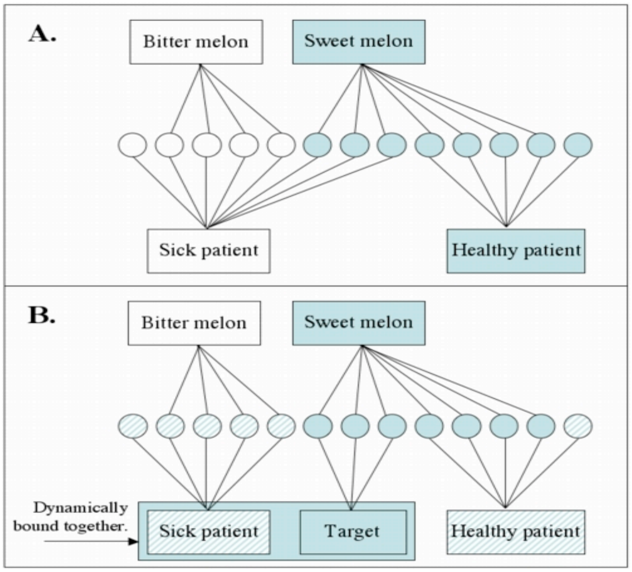

Figure 6: (A) The control condition of Experiment 2 implemented in LISA architecture; (B) The word condition of Experiment 2.

Using LISA to understand how language specifically interacts with analogical reasoning is a first pass attempt to look at the impact of language on cognition. Models of analogical research should be able to account for effects of context, similarity, and relational language working as a coherent system. Connecting the themes of analogical research into a computational model is a practical way of using previous research to constrain future proposals. Whether cognition with words occurs primarily in the mind or in seamless flow with external scaffolding, models of conceptual transfer should be sensitive to both the "handle"-like aspects of language as well as the "baggage" that comes with it.

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