

# **Is This A Dax Which I See Before Me? Use Of The Logical Argument Disjunctive Syllogism Supports Word- Learning In Children And Adults**

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## **Abstract**

The past fifteen years have seen a proliferation of proposed word-learning constraints hypothesized to guide a word-learner to the correct referent of a newly heard word. One such class of constraints derives from the observation that word-learners of all ages prefer to map novel labels to novel objects in situations of referential ambiguity. In this paper I use eye-tracking to document the mental computations that support this word-learning strategy. Adults and preschoolers saw images of known and novel objects, and were asked to find the referent of known and novel labels. Experiment 1 shows that adults systematically rejected a known distractor (e.g. brush) before mapping a novel label (e.g. "dax") to a novel object. This is consistent with the proposal that participants worked through a Disjunctive Syllogism (i.e. Process-of-Elimination) to motivate the mapping of the novel label to the novel object. Experiment 2 presents a detailed account of the information-processing involved on these trials, and shows that processing is similar for adults performing an explicit Disjunctive Syllogism (e.g. "the winner is not the iron") and an implicit Disjunctive Syllogism (e.g. "the winner is the dax"). Experiment 3 reveals that, when asked to "Find the dax," there is an effect of the word-length of the distractor object's known label on response time. This suggests that participants retrieved the label of the known object and rejected it before mapping the novel label to the novel object. Finally, Experiment 4 reveals that similar processes govern adults' and preschoolers' mapping of novel labels. Taken together, these results suggest that word-learners use Disjunctive Syllogism, rather than a parallel competition among possible referents, to motivate the mapping of novel labels to novel objects.

Key Words: Mutual Exclusivity, Disjunction, Syllogistic Reasoning, Word-Learning, Preschoolers, Deduction, Negation

## Introduction

During the past fifteen years, the literature on word-learning has seen a proliferation of constraints proposed to limit a word-learner's hypotheses of what a new word might refer to. These constraints attempt to meet an inductive challenge: how does a word-learner arrive at the correct interpretation of a new word, the interpretation shared by the language community? When a child hears the word "cup" for the first time, how does she figure out that it refers to middle-sized drinking receptacles that may lack a handle, rather than tables, blueness, plastic, or orange-juice? Children are systematic in the hypotheses they will entertain as to the meaning of a new word. As an infinite number of meanings are conceivable, constraints may help guide which hypotheses the child will actually consider.

The mechanisms proposed to guide word-learning range from attentional biases like salience (Hollich, Hirsh-Pasek & Golinkoff, 1998; Nelson, 1988; Plunkett, 1997; Samuelson & Smith, 1998; Smith, 1995), the nonlinguistic directing of attention through pointing (Mervis, Golinkoff & Bertrand, 1994) and the direction of a speakers' gaze (Baldwin, Markman, Bill, Desjardins, Irwin, & Tidball, 1996), to specific constraints on the lexicon (Clark, 1983; Markman, 1990; Markman, 1992; Markman & Hutchinson, 1984; Waxman & Booth, 2000) and more global constraints on construal through theory of mind (Bloom, 2000; Markson & Bloom, 1997) and pragmatic inference (Diesendruck & Markson, 2001; Clark, 1990; Tomasello & Barton, 1994). As the diversity in these proposals suggests, there is an ongoing debate concerning the proper placement of word-learning constraints in the cognitive hierarchy. Is word-learning guided by mechanisms that are specifically designed for the challenge of learning new words (Waxman & Booth, 2000; Waxman & Booth, 2001; Booth & Waxman, 2002) or by domain general constraints that operate throughout cognition (Bloom & Markson, 2001; Markson & Bloom, 1997; Nelson, 1988; Smith, Jones & Landau, 1996)? Because of this debate, redundant mechanisms at multiple levels of cognition have been proposed to account for the same behavior in young word-learners. While it seems likely that constraints are working on multiple levels, such a proliferation has led to some confusion. In many cases, theorists agree on the overt behavior of word-learners and on the output of a constraint, but they have had little way of deciding at which level the constraint is operating. In this article I consider one such case, word-learners' tendency to map novel labels (i.e. labels that they have not heard before) to novel objects (i.e. objects that do not have a known label).

The tendency to map a newly heard word to an object that does not have a known lexical entry is a

productive one for learning new words. Imagine that there are two objects on the table in front of you (a brush and an object you do not know the name of). If I asked you to "hand me the brush," you could easily recognize this known label and give me the object requested. Seventeen-month-old infants succeed at such a task (Halberda, 2003; Mervis & Bertrand, 1994). But, if I asked you to "hand me the dax," how would you decide which of the two objects I was referring to? Adult intuition tends to be that the novel label "dax" refers to the novel object on the table, and children as young as 17 months of age will also spontaneously reach this conclusion and prefer to map the novel label "dax" to the novel object (Halberda, 2003; Mervis & Bertrand, 1994; *see also* Markman, Wasow & Hansen, 2003). But, how do infants and adults reach this conclusion? What is the principle that guides a word-learner to map a novel label to a novel object and what are the mental computations that are needed to support the use of such a principle?

As is the case with word-learning constraints in general, the strategy of mapping novel labels to novel objects has inspired a proliferation of proposed constraints throughout the literature. Currently, there are four proposals as to the principle that motivates this strategy: Mutual Exclusivity (Markman & Wachtel, 1988), Contrast (Clark, 1993), a Pragmatic Account (Diesendruck & Markson, 2001), and the Novel-Name Nameless-Category Principle (Golinkoff, Hirsh-Pasek, Bailey & Wenger, 1992). Each of these principles tends to make the same behavioral predictions (*but see* Mervis, Golinkoff & Bertrand, 1994). For instance, in the example above, each principle predicts that word-learners will prefer to map the novel label "dax" to the novel object. But, they make this prediction for different reasons. Each posits a different motivation for this behavior and each makes a commitment to some underlying computational structure that supports the principle's use.

The debate over these proposals has focussed almost exclusively on the different motivations they posit for the mapping of novel labels to novel objects and not on the possible mental computations that would be needed to support the principles' use. Because young children have a somewhat limited behavioral repertoire, it has been difficult to find a measure that will allow one to observe the underlying cognitive processes that support a word-learning constraint. For the strategy of mapping novel labels to novel objects, previous studies have utilized categorical measures where either increased haptic manipulation (pointing, playtime) (Golinkoff et al, 1992; Markman & Wachtel, 1988; Mervis et al., 1994; Mervis & Bertrand, 1994; Merriman & Bowman, 1989) or increased visual attention to an object (Baldwin & Markman, 1989; Halberda, 2003; Hirsh-Pasek, Golinkoff & Hollich, 1999) has been used as a measure of referent choice.

This work has been invaluable in showing: 1) that constraints exist 2) that they are used over the course of word-learning from infancy through adulthood (Golinkoff et al., 1992; Mervis & Bertrand, 1994; Halberda, 2003; Merriman & Bowman, 1989), 3) that they are used appropriately by second language learners (Au & Glusman, 1990), and 4) that constraints can be overridden (i.e. that they do not operate in an "all or none" fashion) (Gathercole, 1989; Golinkoff, Mervis & Hirsh-Pasek, 1994; Littschwager & Markman, 1994; Markman & Wachtel, 1988; Nelson, 1988). Categorical measures can reveal the presence and the output of a constraint, but they cannot reveal the computations that support a constraint's use.

While the proponents of Mutual Exclusivity, Contrast, a Pragmatic Account and the Novel-Name Nameless-Category principle have all suggested some computational structure that underlies the use of the principle, these suggestions have remained untested as, to date, there has been no behavioral measure that might reveal them. In the present article I hope to provide such a measure. In what follows I attempt to develop the suggestions of these proposals into specific computational accounts and to bring behavioral evidence to bear on deciding among them.

## Outline of the principles

Mutual Exclusivity (ME) is the principle that every object has just one name (Markman & Wachtel, 1988). While able to be overridden given explicit evidence to the contrary, this principle may guide word-learners first hypotheses concerning the meaning of a new word (Littschwager & Markman, 1994). Upon hearing a novel label, ME motivates a word-learner to reject objects that already have a known label. When presented with a brush and a novel object and asked to "hand me the dax," a word-learner utilizing ME may reason as follows: "The novel label 'dax' either refers to the brush or to the novel object. 'Dax' can not refer to the brush because the brush already has a name (i.e. 'brush') and according to ME it cannot receive another one. Therefore, the novel label 'dax' must refer to the novel object," (Halberda, 2003; Markman, 1990).

The computational structure suggested here is the logical argument structure Disjunctive Syllogism (i.e. *Modus Tollendo Ponens*). Disjunctive Syllogism is any argument of the form: A or B, Not A, Therefore B. More generally known as process of elimination, Disjunctive Syllogism motivates a conclusion through the systematic rejection of all other possibilities. The proponents of Contrast and a Pragmatic Account have also suggested mental computations that can be understood as instantiations of Disjunctive Syllogism.

Contrast is the principle that all lexical entries contrast in meaning (Clark, 1990; Clark, 1993). When faced with a brush and a novel object and asked to "hand me the dax," a word-learner using Contrast would avoid taking "dax" to be synonymous with the known lexical entry "brush". Contrast would be satisfied if the label "dax" was taken to refer to a part of the brush that does not have a known label, or by taking "dax" to be labeling the brush under a different sense than basic-level-object kind (e.g. 'Horse-hair brush'). Thus, in order to capture the mapping of the novel label "dax" to the novel object, Contrast may make use of Markman's Whole Object constraint (Clark, 1990 pg. 423; Markman, 1989; Markman, 1990). This constraint motivates a word-learner to first assume that a novel label refers to a basic-level kind. Clark has described the mental computations underlying this mapping as follows: "When children hear new words, they assume that those words contrast with ones they already know and that they must therefore map onto hitherto unlabeled conceptual categories." (Clark, 1983). Clark has suggested that the principle of Contrast exerts its effect by "eliminating a host of possibilities [i.e. known labels] that could not be eliminated otherwise," (Clark, 1990; Clark, 1993). When faced with a brush and a novel object and asked to "look at the dax", a word-learner using Contrast might reason as follows: "the label 'dax' must refer to an as yet unnamed category. It can not refer to the brush (basic-level kind) because the brush already has a name. Therefore, because I prefer to take "dax" as a label for a basic-level kind, "dax" must refer to the novel object." The mapping of the novel label to the novel object would be motivated via the rejection of the familiar object (e.g. brush).

A Pragmatic Account offers a different motivation for the rejection of familiar objects as possible referents of a novel label. Under the Gricean maxims of communication and the principle of cooperation, speakers should use familiar terms when available (Grice, 1975). Diesendruck and Markson (2001) have suggested that, when presented with a brush and a novel object and asked to "show me the dax," a word-learner utilizing pragmatics would reason as follows: "If the experimenter had wanted me to pick up the [brush], she would have asked me to show her the ['brush']. Given that she asked me for a dax, I inferred that she must have wanted me to give her the other object [i.e. the novel object]". Here again we see that the argument structure is a Disjunctive Syllogism: 'Dax' either refers to the brush or to the novel object. 'Dax' does not refer to the brush (via the implicature: if you had meant brush you would have said 'brush'). Therefore 'dax' refers to the novel object.

It is important to note that, while the above quotations present explicit verbal reasoning, a word-learner need not be a conscious hypothesis-tester in

order to utilize a word-learning constraint. By suggesting that Disjunctive Syllogism underlies the mapping of novel labels to novel objects for Mutual Exclusivity, Contrast and a Pragmatic Account, I do not mean to imply that a word-learner must be an explicit hypothesis-tester. Disjunctive Syllogism is an argument structure that may describe the order of mental computations on any cognitive level. Certainly these computations may be explicit and conscious, but they might just as easily be encapsulated and subconscious.

The fourth principle, the Novel-Name Nameless-Category principle (N3C), does not rely on Disjunctive Syllogism. It denies that the rejection of known objects is a necessary step in mapping novel labels to novel objects (Mervis & Bertrand, 1994). N3C is the principle that word-learners are positively motivated to map novel labels to novel objects (Golinkoff et al., 1992). Thus, N3C posits the strategy of "Map-Novely-to-Novely". Mervis and Bertrand (1994) suggest that, "the child hearing a word that he or she does not know in the presence of an object for which he or she does not yet have a name is sufficient; the child is motivated to map the new word to [the novel object]." I will reference this strong version of N3C throughout the work that follows. Unlike Mutual Exclusivity, Contrast, and a Pragmatic Account, a word-learner utilizing N3C would not have to reject the familiar object (e.g. brush) as a possible referent for the novel label "dax" before deciding to map the novel label "dax" to the novel object. More specifically, according to N3C, a representation of the form "not A" (e.g. "not the brush) should play no causal role in the mapping of novel labels to novel objects. Because there are many computational structures that might capture this spirit of "Map-Novely-to-Novely," I will defer discussion of its possible implementations to the General Discussion.

Thus, three of the principles proposed to motivate the mapping of novel labels to novel objects may be supported by Disjunctive Syllogism: Mutual Exclusivity, Contrast, and a Pragmatic Account. The predictions of Disjunctive Syllogism have yet to be tested. What patterns of behavior might be indicative of Disjunctive Syllogism?

### Predictions of Disjunctive Syllogism

Disjunctive Syllogism holds that the rejection of referents with known labels (e.g. brush) is a necessary step on the way to inferring the referent of a novel label (e.g. "dax"). A word-learner performing a Disjunctive Syllogism would need to motivate the mapping of a novel label to a novel object via an exhaustive process of elimination. Some behavioral predictions follow. Consider the case where a word-learner is presented with a known object (e.g. brush) and a novel object and asked to "point at the dax."

Because Disjunctive Syllogism requires the word-learner to motivate the mapping of the novel label "dax" to the novel object via a process of elimination, the word-learner would be required to bring the known object (e.g. brush) into the focus of attention in order to evaluate it and reject it as a possible referent of the novel label "dax". Thus, according to Disjunctive Syllogism, the rate-determining step for mapping a novel label to a novel object should be the time needed to perform this evaluation and rejection.

There is an alternative to this prediction. Notice that for N3C, no such rejection is required and the rate-determining step should involve the degree of novelty of the label "dax" and of the novel object and not necessarily have any relation to the accessibility of familiar object names (e.g. "brush"). In the following experiments I layout and test a number of specific predictions that follow from Disjunctive Syllogism's requirement that word-learners reject familiar objects (e.g. brush) on the way to mapping novel labels to novel objects.

Behaviors that may correlate with the evaluation and rejection required by Disjunctive Syllogism are the direction of a word-learner's gaze and the reaction time to reject familiar object distractors. If word-learners are required to think "not the brush," before mapping the novel label "dax" to the novel object, an eye-movement to the brush may correlate with this shift in attention and the time required to reject this object may be a function of the accessibility of the object's known label (i.e. "brush"). I will use a variety of such measures to test the predictions of Disjunctive Syllogism.

Eye-tracking has been used in recent years to study on-line speech processing in children and adults (Allopenna, Magnuson, Tanenhaus, 1998; Dahan, Swingley, Tanenhaus & Magnuson, 2000; Fernald, Pinto, Swingley, Weinberg & McRoberts, 1998; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995). This work has been motivated by the discovery that eye-movements to relevant areas of a visual scene often correlate with the underlying mental computations necessary for language comprehension and production. That is, as unfolding speech marks information about the environment (e.g. "Put the frog on the beaker"), a listener will tend to shift their gaze to relevant areas of the visual scene (Griffin & Bock, 2000). For example, as a participant listens to a spoken word (e.g. "beaker") eye-movements to potential target objects (e.g. beaker, speaker, beetle, carriage) are made as a function of the phonetic similarity between the speech-stream and the object's known label (i.e. 'beaker', 'speaker' etc.). The linking of these eye-movements to the mental processes underlying spoken word-recognition has proven to be robust in situations where eye-movements are "cheap", that is, when objects are close such that moving the eyes takes little effort.

While patterns of eye-movements do not necessarily indicate the full computational processes involved in language comprehension, a promising indication that participants' eye-movements may help constrain the models we build comes from the work on spoken word recognition. For cases such as the "beaker" example above, the pattern of participants' eye-movements to potential targets across time has been fit to the computational predictions of continuous mapping models such as the TRACE model, a connectionist architecture that models word recognition (Allopenna, Magnuson, & Tanenhaus, 1998; McClelland & Elman, 1986). In this case, eye-movements correlate quite closely with the predictions of a rigorous computational model.

Further support for my suggestion that patterns of eye-movements may correlate with the mental computations underlying Disjunctive Syllogism and the use of a word-learning constraint comes from work on inductive reasoning. As reviewed by Grant and Spivey (2003), patterns of eye-movements have been found to correlate with the strategies that subjects adopt when solving problems in mental rotation (Just & Carpenter, 1985), geometrical reasoning (Epelboim & Suppes, 1997) and diagram-based reasoning (Grant & Spivey, 2003).

Until now, studying the underlying computational structure of a word-learning constraint as it operates '*in vivo*' has not been possible. This is because previous methods have relied primarily on categorical data (i.e. increased looking to or reaching for an object). Such measures do not allow one to observe the use of a principle as the mental computations which support it unfold. The method of eye-tracking may overcome this limitation.

Adopting the three-levels description of complex systems discussed by Marr (1982) (i.e. *computation, algorithm, implementation*), the present work focuses on one possible *algorithm*, Disjunctive Syllogism, that may underlie the word-learning strategy of mapping novel labels to novel objects. Throughout this work I will use the locution "mental computations" to refer to the transformations that the mental *algorithm* performs as it moves from input to output. The challenge for the present work is not to decide which particular principle (Contrast, ME, a Pragmatic Account, or N3C) guides the intuitions of word-learners. Rather, it is to provide evidence that may reveal the mental computations that underlie this strategy.

## Experiment 1

Because the strategy of mapping novel labels to novel objects continues through adulthood (Golinkoff et al, 1992; Markman & Wachtel, 1988;

Mervis et al, 1994; Merriman & Bowman, 1989), adults offer us the opportunity to study the mental computations underlying the mature strategy. Experiment 1 is a simple test of the hypothesis that eye-movements may correlate with the mental operations of Disjunctive Syllogism. Will adults systematically fixate and reject a known object distractor (e.g. brush) prior to mapping a novel label to a novel object?

## Method

### Participants

Participants were 20 college students (10 male) whose first language was English (mean age = 23 yr., range = 18- to 31-yr.). Adults were invited to participate by posters and personal contact within the campus of New York University. An additional 6 adults participated but were removed from the sample for the following reasons: failure to follow directions (5) (e.g. talking, remaining fixated to a single screen throughout the study) and equipment failure (1).

### Stimuli

Visual stimuli consisted of 48 computer generated "3-D" objects from the TarrLab Object Data Bank (1996) displayed on two computer monitors. Twelve of these were novel objects that I constructed in the laboratory by combining parts of known object images to create nameless artifacts (see Figure 1 for an example).

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Auditory stimuli consisted of 24 labeling phrases recorded by a native English speaker. The target label appeared in sentential final position after one of four carrier phrases ("Where is the \_\_\_\_?" "Find the \_\_\_\_?" "Look at the \_\_\_\_?" "Which one is the \_\_\_\_?") that were used randomly throughout the study. Each object and each target label appeared only once during the study.

### Procedure

Participants were tested in a sound-attenuated room. They sat facing two computer monitors which were approximately 50 cm away and 72 cm apart at their centers. Participants were told that they were participating in a word-recognition game. Their task was simply to follow the instructions to "Look at the [target]". Participants were told that some of the objects were very common while others were less so. During each trial two objects appeared, one on each monitor, simultaneously. After a 50msec delay, an auditory stimulus was played that correctly labeled only one of the objects (e.g. "Look at the [brush]"). Participants typically fixated both objects before the label was spoken (73% of all trials). Following label onset, comprehension looking (i.e. percent looking to the labeled target) was measured for 2-s. After this 2-s measure, both objects disappeared simultaneously. No feedback was given.

After 4 practice trials, participants saw 24 test trials. On 12 of these trials, both objects were familiar (e.g. cup and ball). On the other 12 trials, one object was familiar and the other novel (a constructed image e.g. Figure 1). The familiar object was the labeled target on 6 of these trials and the novel object was the target for the other 6. Thus, participants were asked to identify 18 familiar referents and 6 novel referents over the course of the study. Each object appeared only once during the study. Table 1 lists the known and novel object pairs used in Experiment 1.

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Test trials were pseudo-randomized to ensure that the target was not located on the same side for more than two trials in a row. Two different orders were constructed and an equal number of participants completed each order. Stimulus presentation was controlled by a Macintosh computer using Psyscope software (1994).

Participants' looking was recorded by a video camera concealed between the two monitors. Looking was coded from videotape, frame by frame, at 30 frames per second using QuickFrame (Halberda, 2003b) and MacShapa software (Sanderson, 1994). Coders were blind as to the location of the target. Eight participants were coded independently by two coders and intercoder reliability, measured as percentage of total frames in agreement within a trial, ranged from 93-99%.

In addition to this looking-time measure, adults were administered a questionnaire following the study to assess their meta-linguistic awareness of the strategy they used. Participants were asked if they had noticed anything strange about any of the objects or

names used in the study (all participants mentioned not knowing some of the objects and that some of the names were strange). They were then asked how they knew which object to look at when a strange name had been used.

## Results

If adults used the strategy of mapping novel labels to novel objects then when presented with a novel and a familiar object (e.g. phototube and brush) and asked to "look at the dax," participants should successfully increase looking to the novel object (e.g. phototube) above their baseline preference<sup>1</sup>.

Within a trial, looking to the two objects prior to label onset served as a within trial measure of baseline image preference (i.e. from image onset to label onset). Increased looking to the target object after label onset served as a measure of label comprehension (i.e. from label onset to image offset). Percent looking was computed as time spent looking at the target object divided by the total time spent looking at either object. Thus, chance looking both before and after the label was 50%.

Subject means for percent looking to the target object both before and after label onset were computed for each Trial Type (known target with known distractor, known target with novel distractor, and novel target with known distractor). These means entered into a 3 Trial Type X 2 Measurement Period (before and after label onset) X 2 Trial Order repeated measures ANOVA<sup>2</sup>. There was a main effect of Measurement Period,  $F(1,18) = 288.45, p < .001$  as adults increased their looking to the labeled target above their baseline preference on all trial types. There was no effect of Trial Type, or Order. Planned t-tests showed that the two types of Known Label trials (i.e. known target with a known distractor, and known target with a novel distractor) did not differ and they were therefore collapsed as "Known Label trials" throughout. As seen in Figure 2, adults successfully increased looking to the labeled target on both Known and Novel Label trials above their baseline preference: Known Labels, +42.2%,  $t(19) = 15.78, p < .001$ ; Novel Labels, +34.8%,  $t(19) = 9.90, p < .001$ . Therefore, they successfully mapped novel labels (e.g. "dax") to novel objects (e.g. phototube).

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<sup>1</sup> I will refer to an example of a novel object, a phototube, throughout, although the objects used in the study were nameless constructed artifacts (e.g. Figure 1).

<sup>2</sup> All statistical tests were performed at the significance level  $p < .05$  however, keeping with current trends in psychology, I have reported  $p$ -values at their maximum level of significance up to  $p < .001$ .

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What are the mental computations that led adults to map novel labels (e.g. "dax") to novel objects (e.g. phototube)? If Disjunctive Syllogism supports this word-learning strategy then participants must motivate the mapping of the novel label to the novel object via rejection of the familiar object (e.g. "dax does not refer to the brush"). If rather, as N3C suggests, participants are positively motivated to map a novel label to a novel object, no rejection is required (Mervis & Bertrand, 1994). Participants have, in general, fixated both objects before label onset. At the time of novel label onset (e.g. "dax") participants will tend to be fixating either the familiar or the novel object (e.g. brush or phototube). Critically, if Disjunctive Syllogism underlies the mapping of novel labels to novel objects, on trials where participants happen to be fixating the novel object (e.g. phototube) at the time of novel label onset (e.g. looking at phototube, hearing "dax"), they should show a tendency to 'double-check' the familiar object distractor (e.g. brush). That is, participants should shift fixation to the familiar object (e.g. brush), reject it, and then shift fixation back to the novel target (e.g. phototube).

Because participants have already had an opportunity to fixate the familiar object before hearing the novel label (e.g. "dax"), a double-check is not necessary for them to reach a decision. Participants could maintain fixation on the novel object either because they are positively motivated to Map-Noveltly-to-Noveltly or because they performed a Disjunctive Syllogism from memory. However, eye-movements to the familiar object (e.g. brush) may correlate with the necessary shift in attention required by Disjunctive Syllogism as participants reject the brush as a possible referent of the novel label "dax". I therefore predict a significant increase in double-checks on target-fixated Novel Label trials (where rejecting the distractor is a necessary step in the inference) compared to target-fixated Known Label trials (where rejecting the distractor would not be necessary). That is, the predicted increase in double-checks on target-fixated Novel Label trials (looking at phototube, hearing "dax") will be relative to participants' baseline tendency to double-check the distractor object on target-fixated Known Label trials (looking at ball, hearing "ball").

Figure 3 displays the frame-by-frame coding of participants' looking throughout Known and Novel Label trials for those trials on which participants happened to be fixating either the target or the distractor object at the time of label onset. Because

participants do not know which of the two objects will be the target on any given trial, on half of the trials they happened to be looking at the target at the time of label onset, and on the other half the distractor. On only 10% of trials were adults looking at neither, and these trials are not included in Figure 3.

On target-fixated Known Label trials (looking at ball, hearing "ball"), participants should have no need to double-check the distractor (e.g. cup). This is the pattern seen in Figure 3a. Adults double-checked the known object distractor (e.g. cup) on only 16% of target-fixated Known Label trials (looking at ball, hearing "ball") (SE = 3.24).

For target-fixated Novel Label trials (looking at phototube, hearing "dax"), Disjunctive Syllogism predicts that participants should show an increased tendency (compared to target-fixated Known Label trials) to 'double-check' the known object distractor (e.g. brush) before returning gaze to the novel target (e.g. phototube). This is the pattern seen in Figure 3b. Adults double-checked the known object distractor before returning gaze to the novel target on 76% of target-fixated Novel Label trials (SE = 7.28). This increase in double-checks on target-fixated Novel compared to target-fixated Known Label trials was significant as measured by a paired-samples t-test:  $t(19) = 6.79, p < .001$ , and is consistent with the predictions of Disjunctive Syllogism.

In Figure 3, percent looking does not drop down to 24% on target-fixated Novel Label trials (looking at phototube, hearing "dax") as might be expected by simply subtracting the percent of trials on which participants double-checked (76%) from all possible trials (100%). This is because different subjects double-checked the known object distractor at different times during the trial. It is the significant increase in double-checks and the overall pattern of shifts in gaze that are consistent with Disjunctive Syllogism.

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It is important to note that double-checking the distractor object is not necessary on any of these trials. On 78% of target-fixated Novel Label trials (looking at phototube, hearing "dax"), participants had already fixated both the target and the distractor before label onset. They could have worked through the steps of Disjunctive Syllogism in memory and never switched gaze. The fact that they do switch gaze suggests that participants' eye-movements may follow the mental computations of Disjunctive Syllogism as they work through its steps: "The label 'dax' either refers to the brush or the novel object. 'Dax' does not

refer to the brush (because the brush already has a name). Therefore, 'dax' must refer to the novel object."

It is also important that the double-checks observed on target-fixated Novel Label trials (looking at phototube, hearing "dax") were not caused by possible misinterpretations of the target label. On target-fixated Novel Label trials (looking at phototube, hearing "dax"), 72% of adults' double-checks occurred after the offset of the novel label (dotted line in Figure 3), by which time participants would have processed the entirety of the novel label.

Adults were given a short questionnaire following their participation in the study to assess their meta-cognitive awareness of the strategy they had used on Novel Label trials. Participants were asked if they had noticed anything strange about the objects or names used in the study. All participants mentioned that they did not know what some of the objects were and that they had not heard of some of them before. They were then told that the experimenter had observed through the camera that they had chosen to look at the novel objects when presented with a novel label. Participants were asked why they had done so. Answers were expected to fall into one of two categories: Map-Novelty-to-Novelty (e.g. "Because I didn't know any name for that object," "Because it was weird looking,") or Disjunctive Syllogism (e.g. "Because I knew that it couldn't be the brush (i.e. familiar object)."). 100% of participants gave answers consistent with Disjunctive Syllogism.

## Conclusions

Adults appear to reject familiar object distractors (e.g. brush) before mapping a novel label (e.g. "dax") to a novel object (e.g. phototube)<sup>3</sup>. Both the pattern of double-checks observed on target-fixated Novel Label trials, and participants' own subjective verbal report are consistent with the proposal that Disjunctive Syllogism underlies the mapping of novel labels to novel objects.

## Experiment 2

The pattern of double-checks observed in Experiment 1 suggests that Disjunctive Syllogism

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<sup>3</sup> A separate experiment (Halberda, 2002) revealed similar results when word-learners were presented with 4 possible referents on Novel Label trials (e.g. "dax"). That is, adults systematically fixated and rejected all 3 known object distractors (e.g. brush, pen, banana) before mapping a novel label (e.g. "dax") to a novel object (e.g. phototube).

may underlie the mapping of novel labels to novel objects. But, a far more rigorous test of this hypothesis is possible. If Disjunctive Syllogism underlies the mapping of novel labels to novel objects, the pattern of eye-movements observed as word-learners work through this mapping should match parametrically that observed when participants are required to work through an explicit Disjunctive Syllogism.

Imagine that a participant is presented with two objects (e.g. iron and pumpkin) and asked to "find the winner" between these two. If this participant happened to be looking at the pumpkin and was told, "the winner is not the iron," how would they decide which was the winner? In order to succeed on such a trial, the participant might double-check the iron, reject it from consideration, return gaze to the pumpkin and point to it. The labeling act, "the winner is not the iron," invites subjects to work through an explicit Disjunctive Syllogism. If Disjunctive Syllogism underlies the mapping of novel labels to novel objects, the shifts in gaze observed when subjects are told "the winner is the dax" should match parametrically those observed when subjects are told "the winner is not the iron."

## Method

### Participants

Participants were 10 adults (5 male) whose first language was English (mean age = 23 yr., range = 18- to 31-yr.). Adults were invited to participate by posters and personal contact within the campus of Harvard University. Two additional adults participated but were removed from the sample for the following reasons: failure to follow directions (1) and equipment failure (1).

### Stimuli

Visual stimuli were the same as those used in Experiment 1. Auditory stimuli consisted of 32 labeling phrases recorded by a native English speaker. The target label appeared in sentential final position after one of two carrier phrases ("the winner is the \_\_\_\_" "the winner is not the \_\_\_\_"). Each object and each target label appeared only once during the study.

### Procedure



The procedure was similar to that used in Experiment 1. Participants were told that they were participating in a word game where they would be asked to "Find the winner" between two objects. That is, two objects were presented on each trial and a speech stimulus told participants either, "The winner is the [target]," or "The winner is not the [distractor]." Their task was to figure out which object was the winner, look at it and point to it.

In Experiment 1, double-checking was not necessary on any trial type as participants had generally fixated both objects before label onset. In Experiment 2 I wish to build specific quantitative predictions about the number of switches in gaze necessary to succeed on each trial type. To make switching gaze necessary, during each trial the speech stimulus began before the pictures were presented (e.g. "The winner is the ball."). Approximately 250 msec before the onset of the label ("ball"), two objects appeared, one on each monitor, simultaneously. Participants typically fixated one of these objects before the label was spoken (89% of all trials) and rarely fixated both. Following label onset, comprehension looking was measured for 4s (i.e. 2s longer than in Experiment 1 because participants were expected to need extra time on Negation trials). After this 4s measure, both objects disappeared simultaneously. No feedback was given.

After four practice trials, participants saw 28 test trials. Test trials were similar to the 2 trial types from Experiment 1 (e.g. "the winner is the ball," "the winner is the dax") along with a version of each of these trial types which included explicit negation (e.g. "the winner is not the iron," "the winner is not the tever"). These will be referred to as Known, Novel, Not-Known and Not-Novel trials respectively.

An exact description of the trials presented is as follows. On 12 of the 28 test trials, both objects were known (e.g. cup and ball). On 6 of these trials, participants were told, "The winner is the [known object]." On the other 6, participants were told, "The winner is not the [known object]." On 16 of the 28 trials, one object was known and the other novel (a constructed image e.g. Figure 1). On 4 of these trials, participants were told, "The winner is the [known object]," and on 4 others they were told, "The winner is not the [known object]." On 4 other trials participants were told, "The winner is the [novel object]," and on 4 more they were told, "The winner is not the [novel object]." Trials were pseudo-randomized into two different orders and an equal number of participants completed each order.

Participants' looking was recorded and analyzed as in Experiment 1. Four participants were coded independently by two coders and intercoder reliability, ranged from 92-99%.

Experiment 2 included 2 additional measures not used in Experiment 1. First, participants were asked to both look and point to the winning object on all trials. Reaction time to point was coded along with looking. Second, after completing the study, adults were presented with four post-test trials designed to ask whether participants had successfully learned any of the novel labels. On these trials two of the novel objects that had been labeled during the study appeared, one on each screen. Subjects were asked to point to one of them (e.g. "could you point at the [dax]?") thus testing whether or not they had learned these novel labels during the study. On two of the four trials, both of the novel objects had been presented on a typical Novel Label trial (i.e. "the winner is the [dax]"). On the other two trials both objects had been presented on a Not-Novel trial (i.e. "the winner is not the [tever]"). If subjects successfully pointed to the correct novel object on these post-test trials, this would indicate that they had in fact learned which novel label referred to which novel object and retained these mappings for at least the duration of the study. Further, if participants succeeded on both Novel and Not-Novel post-test trials, this would suggest that participants had mapped the novel label to the novel object over the course of the Not-Novel trials. As in Experiment 1, adults were also given a questionnaire following the study to assess their meta-linguistic awareness of the strategy they had employed.

## Results

### Predictions for point times

In addition to the analyses used in Experiment 1, Experiment 2 affords an analysis of the relative ordering of point times as a function of which object (target or distractor) a participant happened to be fixating at time of label onset.

When presented with a cup and a ball and asked to "point at the ball," it seems clear that the best information to guide a decision to point is in the ball itself. The rate-determining information for deciding to point to a target on Known Label trials (e.g. "ball") should be information about the known object (e.g. ball). This leads to the prediction that point times on target-fixated Known Label trials (looking at ball, hearing "ball") should be faster than point times on distractor-fixated Known Label trials (looking at cup, hearing "ball"). This prediction is independent of the predicted switch in gaze required on distractor-fixated trials (which takes approximately 100 msec to execute). As will be discussed for the case of Not-Novel trials (e.g. "not the tever"), even if participants do not shift gaze, the predicted number of mental

computations for each trial should still determine participants' reaction time to point.

If Disjunctive Syllogism underlies the mapping of novel labels to novel objects, the relative ordering of point times on Novel Label trials (e.g. "dax") should be the inverse of that observed on Known Label trials (e.g. "ball"). Because a word-learner performing a Disjunctive Syllogism must motivate the mapping of a novel label to a novel object via rejection of the familiar object (e.g. "dax" does not refer to the brush), point times on distractor-fixated Novel Label trials (looking at brush, hearing "dax") should be faster than point times on target-fixated Novel Label trials (looking at phototube, hearing "dax"). When trying to decide which object is a "dax", Disjunctive Syllogism predicts that the best information is in the distractor object (e.g. brush).

This same pattern should obtain for Not-Known trials ("the winner is not the iron"). When required to reason over an explicit negation, the rate-determining information for reaching a decision to point should be information about the distractor object (i.e. the object iron when told, "the winner is not the iron").

Notice that this predicted ordering of point times on Novel Label trials ("dax") would not obtain if participants were using the strategy of Map-Novelty-to-Novelty (N3C). While ME, Contrast, and a Pragmatic Account are consistent with Disjunctive Syllogism, N3C proposes that word-learners are positively motivated to map novel labels to novel objects with no explicit rejection of the familiar object (e.g. brush) required. For a word-learner using N3C, the rate-determining information for deciding which object is a "dax" should reside in the novel object itself. For the strategy of Map-Novelty-to-Novelty, the more novel this object is (e.g. phototube) the faster a subject should be to map a novel label to it.

In summary, if adults are using Disjunctive Syllogism to motivate the mapping of novel labels to novel objects, participants should show: 1) above chance looking to the novel object (e.g. phototube) after hearing the novel label (e.g. "dax"), 2) a significant increase in double-checks on Novel and Not-Known trials compared to Known trials, and 3) an inverse ordering of point times on Novel and Not-Known trials compared to Known trials as a function of which object (target or distractor) happened to be fixated at time of label onset. Further support for Disjunctive Syllogism may come from subjects' own meta-linguistic awareness of the strategy they were using.

Results: Looking and pointing

Subject means for percent looking to the target object following target label onset served as a measure of success at the task. Planned t-tests revealed that participants succeeded on all trial types compared to the chance level of 50% looking: Known trials,  $t(9) = 16.61, p < .001$ ; Not-Known trials,  $t(9) = 13.98, p < .001$ ; Novel trials,  $t(9) = 9.69, p < .001$ ; Not-Novel trials,  $t(9) = 2.70, p < .05$ , as shown in Figure 4.

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INSERT FIGURE 4 ABOUT HERE  
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Figure 4 shows that participants successfully mapped novel labels to novel objects, and that they successfully reasoned over explicit negation on Not-Known and Not-Novel trials. Next I ask, what are the mental computations that underlie the mapping of novel labels to novel objects? Is the frame-by-frame looking pattern observed on Novel trials (e.g. "the winner is the dax") similar to that observed on Not-Known trials (e.g. "the winner is not the iron") as Disjunctive Syllogism predicts?

Figure 5 displays the frame-by-frame coding of participants' looking throughout Known (5a), Not-Known (5c), Novel (5b) and Not-Novel trials (5d) for trials on which participants happened to be fixating either the target or the distractor object at time of label onset. These accounted for 95% of all trials.

On the left side of Figure 5, the results from Experiment 1 are replicated for Known and Novel Label trials. Critically, on target-fixated Known trials (looking at ball, hearing "ball"), participants double-checked the distractor (cup) on 36.25% of trials (SE = 12.78). In contrast, participants double-checked the distractor object on 96.8% of target-fixated Novel label trials (looking at phototube, hearing "dax") (SE = 3.13). This difference was significant as measured by a planned paired samples t-test:  $t(7) = 4.56, p < .005$ .

Displayed in Figure 5c, participants also increased their double-checks on target-fixated Not-Known trials (looking at pumpkin, hearing "not iron") (93.75%, SE = 6.25) compared to target-fixated Known trials (looking at ball, hearing "ball") as measured by a planned paired samples t-test:  $t(9) = 4.76, p < .001$ . As predicted by Disjunctive Syllogism, double-checks for target-fixated Novel and Not-Known trials did not differ from each other (96% vs. 93%).

The combination of explicit negation ("not") and novel labels (e.g. "dax") in Experiment 2 allowed for a more detailed analysis of the parametric agreement between the mental computations predicted by Disjunctive Syllogism and the switches in gaze observed on each trial type. Table 2 displays both the

number of mental computations predicted by a serial model of Disjunctive Syllogism (i.e. A or B, not A, Therefore B) and the observed number of switches in gaze (computed by taking subject means for the number of switches in gaze prior to pointing). Combining these predictions with the looking patterns displayed in Figure 5 offers a more detailed account of the underlying computational structure of each trial type.

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#### Known trials

For target-fixated Known trials, participants happened to be looking at the target (e.g. ball) when they heard the target label (e.g. "ball"). All of the required information to motivate the mapping of this label to its referent is present. Participants should not need to explicitly reject the distractor object (e.g. cup). In Table 2, the predicted number of mental computations is 0 and the predicted number of switches in gaze, before the participant points to the target, is also 0. There are, of course, interesting mental computations involved in both image recognition (that the image is a ball), and in speech recognition (that the spoken label is "ball"), but these mental computations would be necessary, *mutatis mutandis*, for all of the trial types displayed in Table 2. Thus, the prediction of 0 mental computations is specifically that all of the information required to reach a decision to point is present in the object fixated (e.g. ball) and the label heard (e.g. "ball"). Participants showed a greater tendency to double-check the distractor on these trials (36%) compared to that observed in Experiment 1 Figure 3 (16%). This is most likely due to the briefer exposure participants had to the objects in Experiment 2 and to the fact that Experiment 2 elicited a greater number of double-checks on all trial types.

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For distractor-fixated Known Label trials, participants happened to be looking at the distractor (e.g. cup) when they heard the label (e.g. "ball"). In this case, one additional computation is predicted. Participants should compute a mismatch between the object fixated (e.g. cup) and the label (e.g. "ball"). This mismatch should motivate 1 shift in gaze, to the target object (e.g. ball). And at this point the same mental computations that were required on target-

fixated Known label trials should be carried out. That is, participants should recognize the target image (e.g. ball) and point to it. Thus, distractor-fixated Known Label trials (looking at cup, hearing "ball") should require exactly 1 more computation than target-fixated Known Label trials (looking at ball, hearing "ball"). This is also seen in Table 2. Participants' point times were significantly faster on target-fixated Known Label trials compared to distractor-fixated Known Label trials as measured by a planned paired samples *t*-test:  $t(9) = 2.59, p < .05$ .

Because distractor-fixated Known Label trials (looking at cup, hearing "ball") require an extra computation, the reaction time to point on these trials should be longer than that observed on target-fixated Known Label trials (looking at ball, hearing "ball"). This is also seen in Table 2. Participants' point times were significantly faster on target-fixated Known Label trials compared to distractor-fixated Known Label trials as measured by a planned paired samples *t*-test:  $t(9) = 2.59, p < .05$ .

#### Not-Known trials

On target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"), the information needed to motivate a decision to point is in the distractor object (e.g. iron). On these trials, participants should shift fixation to the distractor object (e.g. iron). They should reject it from consideration. This rejection should motivate a shift in gaze back to the target (e.g. pumpkin), and then participants should be motivated to point to the pumpkin having completed this process of elimination. Thus, Disjunctive Syllogism predicts 2 mental computations and 2 corresponding shifts in gaze on target-fixated Not-Known trials.

This is the pattern seen in Figure 5 and Table 2. On target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"), participants switched gaze away from the target, double-checked the distractor (e.g. iron) and then returned gaze to the target (e.g. pumpkin) on 93% of trials.

On distractor-fixated Not-Known trials, participants happened to be looking at the distractor (e.g. iron) when they heard the label (e.g. "not the iron"). Disjunctive Syllogism predicts exactly one less computation than it does for target-fixated Not-Known trials. That is, participants should reject the iron from consideration, make 1 shift in gaze to the target (e.g. pumpkin), and be motivated to point to it after having completed this process of elimination. This pattern is also confirmed in Figure 5 and Table 2.

Considering the reaction time to point on Not-Known trials, the relative ordering of point times on these trials as a function of which object (target or distractor) was being fixated at the time of label onset should be the inverse of that observed on Known

trials (e.g. "ball"). Participants should have to work through an explicit Disjunctive Syllogism on Not-Known trials (i.e. "The winner is either the pumpkin or the iron. The winner is not the iron. Therefore, the winner is the pumpkin,"). Because Disjunctive Syllogism requires participants to reject the distractor object (e.g. iron) before inferring the winner (e.g. pumpkin), point times should be faster on distractor-fixated Not-Known trials (looking at iron, hearing "not the iron") compared to target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"). This pattern is the inverse of that predicted for Known trials (e.g. "ball") and it is confirmed in Table 2.

Point times on distractor-fixated Not-Known trials (looking at iron, hearing "not the iron") were significantly shorter than point times on target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"):  $t(9) = 3.21, p < .05$ . On Known trials, participants were faster to reach a decision to point when they started on the target object (e.g. ball). On Not-Known trials, participants were faster when they started on the distractor object (e.g. iron). This interaction proved significant in a 2 Trial Type (Known, Not-Known) X 2 Object Fixated (target, distractor) repeated measures ANOVA on point times:  $F(1, 9) = 13.92, p < .005$  and can be seen in Figure 6.

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Novel trials

Disjunctive Syllogism predicts that the mental computations and shifts in gaze observed on Novel trials (e.g. "dax") should be similar to those seen on Not-Known trials (e.g. "not the iron"). On target-fixated Novel trials (looking at phototube, hearing "dax"), participants should fail to find a match between the novel object and the novel label. This would motivate a shift in gaze to the distractor object (e.g. brush). Participants should then reject the brush as a possible referent for the novel label "dax" using one of three possible word-learning principles that is consistent with Disjunctive Syllogism (i.e. ME "because the brush already has a name," Contrast "because words should contrast in meaning" or a Pragmatic Account "because if the speaker had meant for me to point at the brush the speaker would have said 'brush'"). This rejection of the familiar object would motivate a switch in gaze back to the novel target object. And, by process of elimination, the participant would then be motivated to map the novel label to the novel object. Thus, as with target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"), Disjunctive Syllogism predicts 2 mental

computations and 2 corresponding shifts in gaze on target-fixated Novel trials (looking at phototube, hearing "dax").

This is the pattern seen in Figure 5 and Table 2. The pattern of double-checks on target-fixated Novel trials (looking at phototube, hearing "dax") matches that seen on target-fixated Not-Known trials (looking at pumpkin, hearing "not the iron"). Participants double-checked the distractor object, rejected it, and returned gaze to the target object before pointing on 96% of target-fixated Novel trials. This was a significant increase in double-checks compared to target-fixated Known trials (looking at ball, hearing "ball") as measured by a planned paired samples t-test:  $t(7) = 4.56, p < .005$ .

On distractor-fixated Novel trials, participants happened to be looking at the distractor (e.g. brush) when they heard the novel label (e.g. "dax"). Disjunctive Syllogism predicts exactly 1 less computation than was predicted for target-fixated Novel trials. That is, participants should reject the brush as a possible referent of the novel label "dax". This would motivate a shift in gaze to the target object (e.g. phototube), and participants would be motivated to map the novel label to this novel object having completed the process of elimination. Thus, on distractor-fixated Novel trials (looking at brush, hearing "dax"), Disjunctive Syllogism predicts 1 computation and 1 corresponding shift in gaze. This is the pattern seen in Figure 5 and Table 2.

Because Disjunctive Syllogism predicts 2 mental computations for target-fixated Novel trials (looking at phototube, hearing "dax") and 1 computation for distractor-fixated Novel trials (looking at brush, hearing "dax"), Disjunctive Syllogism predicts that participants' point times should be faster on distractor-fixated Novel trials than on target-fixated Novel trials. This is the same relative ordering that was predicted for Not-Known trials (e.g. "not the iron"), and it is the inverse of that predicted for Known trials (e.g. "ball"). These predictions are confirmed in Table 2 and can be seen in Figure 7. The ordering of point times on Novel trials (e.g. "dax") is the inverse of that observed on Known trials (e.g. "ball") and this interaction proved significant in a 2 Trial Type (Known, Novel) X 2 Object Fixated (target, distractor) repeated measures ANOVA on point times:  $F(1, 7) = 13.48, p < .01$ .

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What allies Not-Known trials (e.g. "not the iron") with Novel trials (e.g. "dax") is the mental computations purported to underlie them. Being told, "the winner is not the iron," invites participants to

work through an explicit Disjunctive Syllogism where by they reject the iron from consideration and point to the target object (e.g. pumpkin). I propose that being told, "the winner is the dax," invites participants to work through a similar Disjunctive Syllogism whereby they reject the distractor object (e.g. brush) as a possible referent of the novel label (e.g. "dax") in order to motivate the mapping of the novel label to the novel object (e.g. phototube) via a process of elimination. Disjunctive Syllogism predicts the similar behavior elicited by these two very different labeling acts.

## Not-Not-Not trials

On Not-Not-Not trials (e.g. "not the tever"), participants were faced with interpreting the labeling act, "the winner is not the [tever]." A serial model, combining an implicit (e.g. "tever") and an explicit (e.g. "not the...") Disjunctive Syllogism would predict that participants must first figure out what a "tever" is before they can figure out what a "tever" is not<sup>4</sup>. On this model, Not-Not-Not trials (e.g. "not the tever") can be construed as a Novel trial (e.g. "tever") combined with a Not-Known trial (e.g. "not the tever [newly learned]"). Participants should first map the novel label "tever" to the novel object using the implicit Disjunctive Syllogism already described for Novel trials. Then participants should deduce which object is not the "tever," using the explicit Disjunctive Syllogism already described for Not-Known trials.

Evidence from Not-Not-Not trials (e.g. "not the tever") is important for two reasons. First, as will be described below, a model of implicit-then-explicit Disjunctive Syllogism predicts a pattern of "triple-checks" for distractor-fixated Not-Not-Not trials (looking at tever, hearing "not the tever"). A pattern of triple-checks will bolster the claim that eye-movements correlate with the underlying mental computations of Disjunctive Syllogism. Second, and more importantly, a model of implicit-then-explicit Disjunctive Syllogism predicts that the relative ordering of point times should return to the order predicted for Known trials (e.g. "ball"). As will be described below, reaction time to point on target-

fixated Not-Not-Not trials (looking at bell, hearing "not the tever") should be faster than point times on distractor-fixated Not-Not-Not trials (looking at tever, hearing "not the tever"). This return to the relative ordering of point times that was observed on Known trials (e.g. "the winner is the ball") would illustrate that it is the number of computations involved and not simply the difficulty of the trial that drives the inversion of relative ordering that has already been noted for Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron"). Both the predicted pattern of triple-checks and the predicted ordering of point times on Not-Not-Not trials (e.g. "not the tever") should serve to dispel concerns that the pattern of double-checks/triple-checks observed may be epiphenomenal or that the relative ordering of point times is uninformative.

On target-fixated Not-Not-Not trials (looking at bell, hearing "not the tever"), a serial implicit-then-explicit Disjunctive Syllogism model predicts that subjects must first decide which object is the "tever" before they can decide which object is not the "tever". Participants should reject the known object (e.g. bell) as a possible referent of the novel label (e.g. "tever"). This would then motivate a switch in gaze to the distractor object (e.g. tever). Participants would then be motivated to map the novel label (e.g. "tever") to the novel object (e.g. tever), having completed this process of elimination. Afterwards, participants would be in a position to reason using the explicit negation (i.e. "the winner is not the tever"). Participants should reject the newly learned novel object (e.g. tever). This would motivate a switch in gaze back to the target object (e.g. bell) and participants should point to the bell as the winner of, "the winner is not the tever". Thus, for target-fixated Not-Not-Not trials (i.e. looking at bell, hearing "not the tever"), the serial model predicts 2 mental computations and 2 corresponding shifts in gaze.

This is the pattern seen in Figure 5 and Table 2. On target-fixated Not-Not-Not trials, participants performed a double-check before pointing to the target on 98% of trials.

On distractor-fixated Not-Not-Not trials (looking at tever, hearing "not the tever"), participants happened to be looking at the distractor object (e.g. tever) when they heard the label (e.g. "not the tever"). Participants should fail to find a match between the object fixated (e.g. tever) and the novel label (e.g. "tever"). This would motivate a shift in gaze to the known object (e.g. bell). Participants should then reject the known object (e.g. bell) as a possible referent for the novel label (e.g. "tever") using one of the principles consistent with Disjunctive Syllogism (Contrast, Mutual Exclusivity, a Pragmatic Account). This would allow participants to map the novel label (e.g. "tever") to the novel object (e.g. tever). A switch in gaze back to the novel object (e.g. tever) may accompany this mapping (i.e. a triple-check).

<sup>4</sup> I have chosen to refer to these two processes as implicit (e.g. "tever") and explicit (e.g. "not the tever") Disjunctive Syllogisms in acknowledgement of the forms of negation involved in each. I use "explicit Disjunctive Syllogism" to reference the contradictory negation marked in the language (e.g. "not the tever"). I use "implicit Disjunctive Syllogism" because the rejection of objects with known labels (e.g. brush) as possible referents of a novel label (e.g. "tever") involves an inductive step derived from the word-learning constraint (e.g. "because every object should have just one name"), implicating an implicit rather than explicit negation.

However, because participants have just fixated this object, a switch in gaze is not necessary in order to make the mapping. Participants could make this mapping in memory. After mapping the novel label (e.g. "tever") to the novel object (e.g. tever), participants should then reason using the explicit negation (i.e. "The winner is not the tever"). Participants should reject the novel object (e.g. tever). This would motivate a switch in gaze back to the target object (e.g. bell), and participants should point to the bell as the target of "The winner is not the tever". Thus, on distractor-fixated Not-Novels trials (i.e. looking at tever, hearing "not the tever") a serial model predicts 3 mental computations and 3 switches in gaze.

The fact that many participants mapped the novel label (e.g. "tever") to the novel object (e.g. tever) in memory is the reason for the one discrepancy between the predicted and observed number of switches in gaze in Table 2. For distractor-fixated Not-Novels trials (looking at tever, hearing "not the tever"), the predicted number of switches in gaze is 3 and the observed number was 1.67. Participants were always looking at the target object (e.g. bell) when they pointed to it as the target (e.g. "not the tever"). On some trials participants made 1 switch in gaze early in the trial to fixate the known object (e.g. bell), then, after a prolonged delay, pointed to the bell. These would be trials where the participant evidently mapped the novel label to the novel object in memory without performing a triple-check. On the remainder of the trials (33%) participants made 3 switches in gaze (i.e. a triple-check), switching gaze back to the novel object before returning and pointing to the known object (e.g. bell). This led to the observed number of switches in gaze being 1.67.

Participants performed a triple-check on 33% of target-fixated Not-Novels trials (looking at tever, hearing "not the tever") suggesting that, while many subjects mapped the novel label (e.g. "tever") to the novel object (e.g. tever) in memory, a shift in gaze back to the novel object sometimes accompanied the making of this mapping. This tendency to perform a triple-check on a subset of distractor-fixated Not-Novels trials (looking at tever, hearing "not the tever") can be seen in Figure 5d. From 2000 msec to 3000 msec, subjects tended to switch gaze back to the novel object (e.g. tever) before pointing (i.e. performed a triple-check).

Participants' tendency to map the novel label (e.g. "tever") to the novel object (e.g. tever) in memory without performing a triple check allowed for an important confirmation of the independence of the pointing and looking measures. According to a model of implicit-then-explicit Disjunctive Syllogism, even if participants do not perform a triple-check they should still have to map the novel label (e.g. "tever") to the novel object (e.g. tever) in memory before reasoning over the explicit negation ("not the tever").

Thus, the serial model predicts that, even in the absence of a triple-check, point times on target-fixated Not-Novels trials (looking at bell, hearing "not the tever") should be faster than point times on distractor-fixated Not-Novels trials (looking at tever, hearing "not the tever").

Therefore, a serial model of implicit-then-explicit Disjunctive Syllogism predicts that the relative ordering of point times on Not-Novels trials (e.g. "not the tever") should be the same as the relative ordering of point times on Known trials (e.g. "the winner is the ball"). This prediction was confirmed in a 2 Trial Type (Known, Not-Novels) X 2 Object Fixated (target, distractor) repeated measures ANOVA on point times which revealed a main effect of the Object Fixated at time of label onset:  $F(1, 8) = 24.63, p < .05$ , and no significant interaction:  $F(1, 8) = 0.01, p = .926$ . As shown in Figure 8, the relative ordering of point times on Not-Novels trials (e.g. "not the tever") and Known trials (e.g. "ball") were the same.

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 INSERT FIGURE 8 ABOUT HERE  
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#### Questionnaire and Post-test

In Experiment 1 participants were asked why they had decided to look at novel objects when presented with novel labels. In Experiment 1, 20 out of 20 subjects gave responses that were consistent with Disjunctive Syllogism (e.g. "because I knew it couldn't be the [brush]"). In Experiment 2, participants were asked the same question, that is, why had they chosen to point to a novel object when presented with a novel label? Ten out of 10 participants gave responses that were consistent with Disjunctive Syllogism. Three subjects went so far as to say, "I used process of elimination."

The lack of an interaction between Trial Type and Object Fixated on Not-Novels trials compared to Known trials supports the hypothesized serial model whereby participants first decide what a "tever" is before deciding what a "tever" is not. Further support for the claim that participants first mapped the novel label (e.g. "tever") to the novel object before reasoning over the explicit negation ("the winner is not the tever") comes from evidence that adults did in fact learn the names of the novel objects on Not-Novels trials ("not the tever"). Each novel object appeared only once during the study. On four post-test trials, participants were asked to point to one of two novel objects. Within each trial, both novel objects had appeared in either a Novel trial ("the winner is the [dax]") or in a Not-Novels trial ("the winner is not the [tever]"). Pointing was compared to the chance level

of 50%. As seen in Figure 9, participants performed at above chance levels for words learned on both Novel and Not-Notel trials: Novel (85%),  $t(9) = 4.58, p < .001$ , Not-Notel (80%),  $t(9) = 3.67, p < .005$ . Furthermore, participants learned the novel words no better if they appeared as a target (e.g. "the winner is the dax") then if they appeared as a distractor (e.g. "the winner is not the tever"):  $t(9) = 0.43, p = .678$ . This supports the hypothesis that participants first decided which object was the "tever", before reasoning over explicit negation, "the winner is not the tever".

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 INSERT FIGURE 9 ABOUT HERE  
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#### Further Analyses

Disjunctive Syllogism makes some further predictions. According to Disjunctive Syllogism, information about the known object distractor (e.g. brush or iron) should be the rate-determining information for detecting the target on both Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron"). It was for this reason that I predicted that the pattern of eye-fixations should be similar for these two types of trials. If information about the known object distractor (e.g. brush) is the rate-determining information for deciding to map a novel label (e.g. "dax") to a novel object (e.g. phototube), then the pattern of looking on target-fixed Novel Label trials (looking at phototube, hearing "dax") should be similar to the pattern observed on distractor-fixed Novel Label trials (looking at brush, hearing "dax") once participants have switched fixation back to the known object distractor (e.g. brush). That is, if looking on target-fixed Novel trials (looking at phototube, hearing "dax") is normalized to the moment at which participants have moved fixation back to the known object distractor (e.g. brush), the pattern of looking that follows should be similar to that observed when participants started on this distractor (i.e. distractor-fixed Novel trials).

In the target-fixed Novel Label trials of Figure 5b (looking at phototube, hearing "dax"), the pattern of looking following the double-check does not show a nice systematic response similar to subjects' rejection of the known object distractor (e.g. brush) on distractor-fixed Novel Label trials (looking at brush, hearing "dax"). Recall that this is because subjects are performing this double-check at different times following label onset (e.g. "dax"). If Disjunctive Syllogism is correct and information about the known object (e.g. brush) is the rate-determining information, then, if we normalize these double-checks to one-another and graph percent-

looking from the moment at which the subject returned their gaze to the known object (e.g. brush), the rate and pattern of shift in gaze back to the target object (e.g. phototube) should match that observed on distractor-fixed Novel Label trials.

In Figure 10, we see the distractor-fixed Novel Label trials from Figure 5 reprinted (looking at brush, hearing "dax"). Also in Figure 10, the target-fixed Novel Label trials that contained a double-check are reprinted (looking at phototube, hearing "dax"), but now with looking time normalized to the moment at which the subject had returned fixation to the known object distractor (e.g. brush). The pattern of looking on these two trial types is similar. Figure 10 reveals the systematic rejection of the known object distractor (e.g. brush) that follows the double-check on target-fixed Novel Label trials (looking at phototube, hearing "dax"). Again, this suggests that participants are motivating the mapping of the novel label (e.g. "dax") to the novel object (e.g. phototube) via rejection of the known object distractor (e.g. brush). Information about the known object distractor (e.g. brush) is the rate-determining information for making this mapping.

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 INSERT FIGURE 10 ABOUT HERE  
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#### Conclusions

Do word-learners work through a Disjunctive Syllogism (i.e. A or B, not A, Therefore B) in order to motivate the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube)? At every level of analysis, the findings of Experiment 2 support the prediction of Disjunctive Syllogism. Participants significantly increased double-checks of the distractor object on Novel trials (e.g. "dax") compared to Known trials (e.g. "ball") (97% vs. 36%). This double-check may correlate with the second step in a Disjunctive Syllogism (i.e. "the label 'dax' either refers to the brush or to the novel object, 'dax' can not refer to the brush because the brush is called 'brush', therefore 'dax' must refer to the novel object,"). The pattern of eye-movements that led to success on Novel trials (e.g. "dax") was parametrically matched to the pattern observed on Not-Known trials (e.g. "not the iron"). These two very different labeling acts should elicit similar behaviors if they both require the participant to perform a Disjunctive Syllogism. The pattern of double-checks in Figure 5 and the switches in gaze displayed in Table 2 matched the number of mental computations predicted by Disjunctive Syllogism for every trial type. The relative ordering

of point times as a function of the object being fixated at the time of label onset (target or distractor) was the same for Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron") again illustrating the underlying similarity of these two trial types. This ordering of point times (i.e. faster RT on distractor-fixated trials) suggested that the rate-determining information for reaching a decision to point on these two trial types resided in the known object distractor (e.g. brush or iron). The relative ordering of point times on Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron") was the inverse of that observed on Known trials (e.g. "ball") and resulted in a significant interaction for each of these trial types (i.e. Novel, Not-Known) compared to Known trials. That information about the known object distractor (e.g. brush) determined participants' ability to map the novel label (e.g. "dax") to the novel object (e.g. phototube) was further confirmed in Figure 10 where participants' looking on target-fixated Novel trials was normalized to the moment at which participants had switched fixation back to the known object distractor (e.g. brush) revealing a pattern of looking that was similar to distractor-fixated Novel trials (looking at brush, hearing "dax"). Furthermore, participants' own meta-cognitive awareness of the strategy they were employing was suggestive of Disjunctive Syllogism, some going so far as to say that they used a "process of elimination" to infer which object the novel label referred to.

The predictions of the hypothesis that Disjunctive Syllogism underlies the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) were further confirmed in participants' responses on the Not-Novel trials (e.g. "not the tever") of Experiment 2. On Not-Novel trials (e.g. "not the tever"), the relative ordering of point times returned to that observed on Known trials (e.g. "ball") as was predicted by a serial model of implicit-then-explicit Disjunctive Syllogism. That is, participants must first map the novel label (e.g. "tever") to the novel object (e.g. tever) using an implicit Disjunctive Syllogism before reasoning over the explicit negation ("the winner is not the tever") using an explicit Disjunctive Syllogism. That participants did in fact map the novel label to the novel object on these trials was shown by their successful learning of these labels as revealed in post-test.

Critically, these results suggest that the rejection of known object distractors (e.g. brush) plays a causal role in the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube). The parametric agreement of Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron") suggests that, in the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube), a representational state equivalent to e.g. "the novel label 'dax' does not refer to the known object brush," determines the rate and success of learning of this new label.

## Experiment 3

Experiment 2 provided evidence that rejection of the known object distractor (e.g. brush) is the rate-determining step for mapping a novel label (e.g. "dax") to a novel object (e.g. phototube). What is the basis for this rejection? The three principles that are consistent with Disjunctive Syllogism all suggest that this rejection involves the retrieval of the familiar objects' known label (e.g. "brush").

According to Mutual Exclusivity, participants reject known objects because of an assumption that each object has only one name (basic-level kind) (Markman & Wachtel, 1988). Thus, in order to reject the known object (e.g. brush), participants must access the known label for this object (e.g. "brush").

Contrast is the assumption that all words should contrast in meaning (Clark, 1990). Thus, when participants reject a known object (e.g. brush) as a possible referent of the novel label (e.g. "dax"), word-learners are required to retrieve the object's known label (e.g. "brush") as well as its semantic content in order to compare this information to the hypothesized semantic content for the novel label (e.g. "dax").

A Pragmatic Account offers that word-learners reject known object distractors for pragmatic reasons: "if the experimenter had meant for me to pick the [brush], they would have said ['brush']" (Diesendruck & Markson, 2001). Here too, word-learners would be required to retrieve the known label (e.g. "brush") in order to motivate this rejection.

Experiment 3 seeks evidence that, in the course of mapping a novel label (e.g. "dax") to a novel object (e.g. phototube), word-learners do in fact retrieve the known label (e.g. "brush") of the known object distractor (e.g. brush). Participants' reaction times to point to the novel target object (e.g. phototube) on Novel Label trials (e.g. "dax") may reveal this retrieval process.

It is well known that word-frequency, word length, and the age at which a word is learned affect the rate of retrieval of familiar labels from the lexicon. The longer a known word is the slower one is to retrieve it from memory (Meyer, Roelofs & Levelt, 2003; Carroll & White, 1973; Morrisson & Ellis, 1995; Morrisson, Ellis & Quinlan, 1992). There is an ongoing debate concerning which of these factors (i.e. word-frequency, word length, age-of-acquisition, and others) correlate most highly with the rate of retrieval. But, these measures are often intercorrelated and any of them may provide a relevant measure of the retrieval of a familiar label (e.g. "brush") from the lexicon. The present Experiment explored the effect of word length. Importantly, the effect of word length on



object naming has been shown to be independent of the ease of object recognition (Meyer et al., 2003).

In Experiment 3, participants were presented with a variety of known object distractors on Novel Label trials (e.g. "dax"). Some of the known objects had relatively short names (e.g. "hat"). Others had longer names (e.g. "flashlight"). If word-learners access the label of the known object distractor (e.g. "hat") in order to reject this object as the referent of the novel label (e.g. "dax"), it should take them longer to retrieve this label when it is long (e.g. "flashlight") than when it is short (e.g. "hat"). This leads to the prediction that participants should be faster to reject known object distractors that have short names (e.g. "hat") than ones that have long names (e.g. "flashlight").

Disjunctive Syllogism predicts that rejection of the known object distractor (e.g. hat) is the rate-determining step for motivating the mapping of the novel label (e.g. "dax") to the novel object (e.g. phototube), and that retrieval of the known label (e.g. "hat") plays a role in this rejection. Therefore, for Novel Label trials ("the winner is the dax"), Disjunctive Syllogism predicts a positive correlation of reaction time to point to the novel target object (e.g. phototube) with the length of the known object distractor's known label (e.g. "hat" vs. "flashlight").

There is an alternative. Consider the strategy of Map-Novelty-to-Novelty (N3C), according to which word-learners are positively motivated to associate novel labels with novel objects. Under the strongest version of this hypothesis word-learners would not be required to evaluate the known object distractor (e.g. brush) as a potential referent for the novel word (e.g. "dax"). As proposed by Mervis and Bertrand (1994), "the child hearing a word that he or she does not know in the presence of an object for which he or she does not yet have a name is sufficient; the child is motivated to map the new word to [the novel object]." For such a strategy, the length of the known label of the distractor object (e.g. "brush") should have no bearing on participants' reaction time to point to the novel target (e.g. phototube), but, importantly, the visual familiarity of the known object distractor (e.g. brush) might.

Under a probabilistic implementation of Map-Novelty-to-Novelty, word-learners might evaluate the visual familiarity of potential referents (e.g. brush and phototube) in order to map the novel label to whichever object is the most visually novel. Such an implementation of Map-Novelty-to-Novelty (N3C) predicts that the visual familiarity of the known object distractor (e.g. brush) might negatively correlate with participants' reaction time to map a novel label to a novel object. That is, the more visually familiar the known object distractor (e.g. apple vs. artichoke), the faster participants should be to decide that the novel object (e.g. phototube) is the most novel.

This allows for a strong prediction for the case of Disjunctive Syllogism versus Map-Novelty-to-Novelty. If Disjunctive Syllogism underlies the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube), participants' reaction time to point on Novel Label trials (e.g. "dax") should be positively correlated with the word length of the known object distractor (e.g. hat vs. flashlight) and should have no relationship to the object's visual familiarity.

## Method

The method was identical to that in Experiment 1 except the use of a wider variety of known object distractors. Adults were asked to point to the correct object.

## Participants

Participants were 11 college students (5 male) whose first language was English (mean age = 21 yr., range = 18- to 28-yr.). Adults were invited to participate by posters and personal contact within the campus of Harvard University. Two additional adults participated but were removed from the sample for the following reasons: failure to follow directions (1) and equipment failure (1).

## Stimuli

Visual and auditory stimuli were identical to Experiment 1, with some additional known objects. Ratings for the visual familiarity of the known object distractors came from the standardized ratings of Snodgrass and Vanderwart (1980). The 3-D objects were models based on the line-drawn stimuli of Snodgrass and Vanderwart (1980), and their ratings therefore offer a good estimate of familiarity.

## Procedure

The procedure was identical to that of Experiment 1. Four adults were coded independently by two coders and intercoder reliability ranged from 90-96%.

## Results

Mean reaction time to point to the novel target object (e.g. phototube) on Novel Label trials was entered into a linear regression with both the visual familiarity and word length of the known object distractor (e.g. brush). As predicted by

Disjunctive Syllogism, this regression revealed that reaction time to point to the novel target was significantly correlated with the word length of the known object distractor's name:  $t(27) = 3.075, p < .005$ , and not with the visual familiarity of this object:  $t(27) = -1.511, p = .14$ .

The significant positive correlation of word length and reaction time to point is shown in Figure 11.

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 INSERT FIGURE 11 ABOUT HERE  
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## Conclusions

Reaction time to point to the novel target object (e.g. phototube) on Novel Label trials (e.g. "dax") was positively correlated with the word length of the known object distractor's known label (e.g. "hat" vs. "flashlight"). This suggests that participants are retrieving the known label in the course of rejecting the known object distractor as a possible referent of the novel label. This result supports the predictions of Disjunctive Syllogism.

Reaction time to point to the novel target object (e.g. phototube) on Novel Label trials (e.g. "dax") did not correlate with the visual familiarity of the known object distractor (e.g. apple vs. artichoke). This suggests that participants are not motivating the mapping of novel labels to novel objects based on a positive motivation to Map-Novelty-to-Novelty. This result also argues against more sophisticated probabilistic versions of Map-Novelty-to-Novelty. That is, word-learners do not appear to be checking the visual novelty of the known object distractor (e.g. brush) in order to map the novel label (e.g. "dax") to the most visually novel object<sup>5</sup>.

## Experiment 4

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<sup>5</sup> That said, word-learners certainly have access to information concerning the visual novelty of objects. This information has been shown to affect label retrieval in both children and adults (Cycowicz, Friedman, Rothstein & Snodgrass, 1997; Snodgrass & Vanderwart, 1980). Follow up studies may indeed find a significant effect of the visual familiarity of the known object distractor (e.g. apple vs. artichoke), but given that such information affects known label retrieval, such a result would be equivocal in supporting either Disjunctive Syllogism or Map-Novelty-to-Novelty.

The results of Experiments 1-3 suggest that Disjunctive Syllogism supports adults' mapping of novel labels to novel objects. A possible criticism of this work is that adults may rely on Disjunctive Syllogism because they have learned this deductive strategy through explicit instruction. Recall that, when asked about the strategy they had employed to infer the referent on Novel Label trials, adults showed meta-cognitive awareness of using a process of elimination. This meta-cognitive awareness might suggest that adults used Disjunctive Syllogism in a 'top-down' manner, relying on an explicitly learned strategy. If this is the case, Disjunctive Syllogism may not support the mapping of novel labels to novel objects in younger word-learners. Thus, a critical test for the hypothesis that Disjunctive Syllogism supports the mapping of novel labels to novel objects across the lifespan requires the testing of younger children who are unlikely to have access to an explicit; learned strategy. Experiment 4 asks, will preschool children also motivate the mapping of novel labels to novel objects via the systematic rejection of known object distractors?

## Method

The method was identical to that in Experiment 1 except that preschoolers were asked to point to and look at the correct object.

## Participants

Participants were 20 preschooler-aged children (10 male) from predominantly English-speaking, middle-class families in the New York area (mean age = 3 yr., 9.5 months, range = 2 yr., 11 months to 5 yr., 2 months). Prior to participation, parents were administered a short inventory of their child's word knowledge composed of the 44 known object labels used in the study. This information was used to check that the known object choices were in fact known. No participants needed to be removed from the study because of a lack of word knowledge. Four additional preschoolers were tested but not included in the final sample due to fussiness (3) and equipment failure (1).

## Stimuli

The stimuli were identical to those in Experiment 1.

## Procedure

The procedure was identical to that in Experiment 1, except that preschoolers were given an extra 250 msec both before and after label onset (e.g. "ball") to look at the objects. Care-givers, if present, sat approximately 4 ft. directly behind the child and were instructed not to speak. This eliminated any potential confound of the care-giver cueing the child's looking. Data were recorded and coded as in Experiment 1. Eight children were coded independently by two coders and intercoder reliability ranged from 94-99%.

## Results

Subject means for percent looking to the target object were constructed as in Experiment 1. Paired-samples t-tests revealed that preschoolers successfully increased looking to the labeled target on both Known and Novel Label trials above their baseline preference: Known Labels, +31.5%,  $t(19) = 15.32$ ,  $p < 0.001$ ; Novel Labels, +29.8%,  $t(19) = 6.95$ ,  $p < 0.001$ . As seen in Figure 12, preschoolers succeeded on both Known and Novel Label trials.

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 INSERT FIGURE 12 ABOUT HERE  
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Did preschoolers use Disjunctive Syllogism to successfully map novel labels (e.g. "dax") to novel objects (e.g. phototube)? Do preschoolers, like adults, show a tendency to double-check the familiar object distractor (e.g. brush) on Novel Label trials (e.g. "dax") before mapping the novel label (e.g. "dax") to the novel object (e.g. phototube)?

Figure 13 shows the frame-by-frame coding of looking-time for Known and Novel Label trials (computed from subject means) for trials on which children happened to be fixating either the target or the distractor object at the time of label onset. These accounted for approximately 90% of all trials.

For target-fixated Novel Label trials (looking at phototube, hearing "dax"), Disjunctive Syllogism predicts that children should show an increased tendency (compared to target-fixated Known Label trials) to double-check the distractor object (e.g. brush) before returning gaze to the novel target (e.g. phototube) and pointing to it. This is the pattern seen in Figure 13. Preschoolers double-checked the known object distractor (e.g. brush) on 59.21% of target-fixated Novel Label trials before mapping the novel label to the novel object ( $SE = 8.31$ ),  $t(18) = 4.50$ ,  $p < 0.001$ .

On target-fixated Known Label trials (looking at ball, hearing "ball"), children happened to be looking at the target object (e.g. ball) when they heard the target label (e.g. "ball"). They should have no need to double-check the distractor object (e.g. cup), and they did so on only 16.54% of these trials ( $SE = 2.96$ ).

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 INSERT FIGURE 13 ABOUT HERE  
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As in Experiments 2 and 3, children were asked to point as well as look at the correct object. According to Disjunctive Syllogism, the relative number of computations required to motivate a point should be a predictor of the relative ordering of point times on target- and distractor-fixated trials. Specifically, I predicted that point times on target-fixated Known Label trials (looking at ball, hearing "ball") should be faster than point times on distractor-fixated Known Label trials (looking at cup, hearing "ball") because fewer computations should be required (see Table 2).

This was the pattern observed for preschoolers' Known Label trials (e.g. "ball"). Point times were significantly faster on target-fixated Known Label trials (mean = 1115 msec) compared to distractor-fixated Known Label trials (mean = 1366 msec) as measured by a planned paired samples t-test:  $t(17) = 5.72$ ,  $p < 0.001$ .

Disjunctive Syllogism predicts the opposite relative ordering of point times for Novel trials compared to Known Label trials (see Table 2). I predicted that point times should be longer for target-fixated Novel trials (looking at phototube, hearing "dax") compared to distractor-fixated Novel trials (looking at brush, hearing "dax"). As seen in Figure 14, this predicted interaction failed to reach significance as measured by a 2 Trial Type X 2 Object Fixated Repeated Measures ANOVA:  $F(1, 13) = .68$ ,  $p = .426$ .

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 INSERT FIGURE 14 ABOUT HERE  
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The non-significant interaction seen in Figure 14 has an explanation that in fact supports the predictions of Disjunctive Syllogism. An inspection of Figure 13b suggests that, on target-fixated Novel Label trials, preschoolers as a group had just enough time to double-check the distractor (e.g. brush), reject it, and return gaze to the target (e.g. phototube) before

trial offset (2250 msec). As seen in Figure 15, the percentage of trials on which children pointed before trial offset was significantly lower for these trials compared to all other trial types: compared to distractor-fixated Novel Label trials (looking at brush, hearing "dax"),  $t(17) = 1.80, p = 0.09$ , compared to distractor-fixated Known Label trials (looking at cup, hearing "ball"),  $t(17) = 3.45, p < .005$ , compared to target-fixated Known label trials (looking at ball, hearing "ball"),  $t(16) = 3.32, p < .005$ . This significant reduction in the number of trials that included a point artificially selected for the target-fixated Novel Label trials (looking at phototube, hearing "dax") on which children happened to point early in the trial. Therefore, if trial length had been long enough, children would have had enough time to point on the remaining target-fixated Novel Label trials (looking at phototube, hearing "dax") resulting in an increased mean reaction time to point.

That children did not have enough time to point on target-fixated Novel Label trials (looking at phototube, hearing "dax") supports the predictions of Disjunctive Syllogism.

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#### Further Analyses

Appendix A contains a discussion of the representations involved in detecting a mismatch between the object fixated (e.g. cup) and the label heard (e.g. "ball") for the various trial types in Experiments 1 and 4 (i.e. adults and preschoolers). This analysis revealed that preschoolers' switches in gaze patterned identically with adults' and thus further supports the claim that a common mechanism underlies the performance of each.

#### Conclusions

The pattern of looking observed in Experiments 1 and 4 (Figures 3 and 13) is consistent with Disjunctive Syllogism because double-checking the distractor object (e.g. brush) was not necessary on these Novel Label trials. Preschoolers had fixated both the known and novel object on 79% of target-fixated Novel Label trials (looking at phototube, hearing "dax") before novel label onset and adults on 78% of these trials. Even if participants were to perform a Disjunctive Syllogism, they could have worked through this Syllogism in memory and never double-checked the known object distractor (e.g. brush). That they do so even when it is not explicitly

necessary supports the hypothesis that eye-movements correlate with the steps in Disjunctive Syllogism: "The label 'dax' either refers to the brush or to the novel object. 'Dax' can not refer to the brush. Therefore, 'dax' must refer to the novel object."

Preschoolers' patterns of fixations within a trial and their reaction times to point to the target objects on these trials supports the hypothesis that, as with adults, Disjunctive Syllogism motivates the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube).

#### General Discussion

What are the mental computations that support the use of word-learning constraints? This question has been difficult for the field to address empirically as, until now, there has been no continuous measure suitable to the limited behavioral repertoire of young children. The method of eye-tracking may help fill this void. A wealth of recent evidence from language comprehension (Alloppenna et al., 1998; Dahan et al., 2000; Fernald et al., 1998; Swingley, Pinto & Fernald, 1999; Tanenhaus et al., 1995), language production (Griffin & Bock, 2000; Meyer, Sleiderink & Levelt, 1998) and human reasoning (Epelboim & Suppes, 1997; Grant & Spivey, 2003; Just & Carpenter, 1985) suggests that eye-movements to relevant areas of a visual scene may correlate with mental processing as it unfolds in real time. In the present article, I have used eye-tracking in an attempt to uncover the mental computations that support the word-learning strategy of mapping novel labels (e.g. "dax") to novel objects (e.g. phototube). For both children and adults, patterns of eye-fixations to potential target objects, reaction times to switch gaze away from fixated targets, and reaction times to point to both known and novel referents revealed of information that can constrain the models that might describe this behavior.

Most if not all word-learning constraints can be thought of as heuristics, e.g. every object should have only one name, words should always contrast in meaning, nouns will typically refer to whole objects rather than parts of objects etc. In order for such commitments to exert an effect on word-learning they must be embedded within mental computations which implement and support their use. Even a heuristic as simple as attentional salience, i.e. that people tend to talk about the most interesting objects in a visual scene rather than the boring ones, can not come for free. Even this bias would require the mental machinery that can compute or compare the relative salience of objects in the scene as well as a learning algorithm engaged in the task of learning new words.

I have suggested that children and adults work through a Disjunctive Syllogism (i.e. A or B, not

A, Therefore B) in order to motivate the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) in cases of referential ambiguity. Adults appear to have some degree of meta-cognitive awareness that they use this strategy, but word-learners would not need to be explicit hypothesis-testers in order to perform a Disjunctive Syllogism. Disjunctive Syllogism is simply the abstract description of a set of computations that might capture mental processing at any cognitive level. Whether participants' use of Disjunctive Syllogism in these cases is part of a more general, conscious, reasoning ability or specific to learning new words remains an open question. If part of a general reasoning ability, the work presented here would extend recent evidence that children below the age of 5 years will spontaneously engage in a process of elimination to solve a non-linguistic reasoning task (Watson, Gergely, Csanyi, Topal, Gasco & Sarkozi, 2001).

Throughout this article, I have contrasted the predictions of the hypothesis that Disjunctive Syllogism supports the mapping of novel labels to novel objects with the predictions of another possible computation, Map-Novelty-to-Novelty (Golinkoff et al., 1992; Mervis & Bertrand, 1994; Mervis, et al., 1994). These two proposals differ in the information that they hold to be the most relevant for deciding on the referent of a novel noun. Disjunctive Syllogism, and the principles that may make use of this computational structure Mutual Exclusivity, Contrast, and a Pragmatic Account, holds that the rejection of known object distractors (e.g. brush) is central to motivating the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube). Map-Novelty-to-Novelty and the N3C principle suggest that information about the novel target object (e.g. phototube) is the most relevant. N3C suggests that word-learners should simply be positively motivated to map novel labels to novel objects. In Experiments 2-4, participants' reaction times to point to novel targets revealed that rejection of the familiar object distractor (e.g. brush) is the rate-determining step for motivating the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube). Participants systematically switched their gaze in order to evaluate and reject the familiar object distractor. Furthermore, in Experiment 3, participants' reaction times to point to novel targets (e.g. "dax") revealed that this rejection involved the retrieval of the distractor object's known label (e.g. "brush") from memory. These results support the predictions of Disjunctive Syllogism.

While the evidence from Experiments 1-4 suggests that adults and preschoolers rely on Disjunctive Syllogism to determine the referent of a novel word, details of their looking patterns suggest that there remains an important possibility for integrating the motivations underlying Disjunctive Syllogism and Map-Novelty-to-Novelty. In Appendix

B I offer evidence that, after rejecting the known object distractor (e.g. brush), children evaluate the novelty of the novel target object (e.g. phototube) before deciding to map the novel label (e.g. "dax") to this object. This suggests a positive proposal that may preserve the spirit of Map-Novelty-to-Novelty while placing it within the framework of Disjunctive Syllogism. That is, when trying to figure out the referent of a novel label (e.g. "dax"), children consider those objects that the speaker might reasonably be referring to. Next, they consider and reject all of those objects that already have a known label (e.g. brush). If there is only one object left then, by process-of-elimination (Disjunctive Syllogism), this must be the target object. But, before children make this mapping, they check to make sure that this object is novel.

My suggestion that the mental computations involved in this word-learning strategy take the form of a Disjunctive Syllogism, i.e. that the computations involve discrete logical computations as opposed to continuous parallel ones, may make some readers uncomfortable. The debate over whether the mind is best described as a propositional, symbolic computing device or a non-propositional connectionist network has been a major focus of the cognitive sciences. Though future modeling work may prove the contrary, some of the results in the present article give me reason to prefer a propositional account of the mapping of novel labels to novel objects.

Here, I present a list of the main results from the present Experiments. These are the results that any model must account for. Below each result, I have noted a prediction or description that is motivated by the hypothesis that Disjunctive Syllogism underlies the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) across development:

- 1) *Word-learners show a significant increase in "double-checks" of the distractor object on target-fixated Novel Label trials (e.g. looking at phototube, hearing "dax") compared to target-fixated Known Label trials (e.g. looking at ball, hearing "ball").*

Disjunctive Syllogism: This shift in gaze correlates with the necessary second step in a Disjunctive Syllogism (e.g. "The label 'dax' either refers to the brush or to the phototube, 'dax' can not refer to the brush, therefore 'dax' must refer to the phototube"). No Disjunctive Syllogism is required on target-fixated Known Label trials (e.g. looking at ball, hearing "ball") and double-checks are therefore rare.

- 2) *Participants' reaction time to point on all trial types (i.e. Known (e.g. "ball"), Novel (e.g. "dax"), Not-Known (e.g. "not*

*the iron"), Not-Novel (e.g. "not the tever") varies as a function of which object (target or distractor) was being fixated at the time of label onset.*

Disjunctive Syllogism: Reaction time to point on these trials varies as a function of when participants gain access to the information relevant for success on each particular trial, which varies as a function of which object (target or distractor) is being fixated at the time of label onset. Success on the four trial types does not result from a parallel competition between all possible referents in which all information is treated equally

- 3) *On Known Label trials (e.g. "ball"), participants are faster to point to the labeled target when they begin their search fixated to the target object (e.g. ball) rather than the distractor object (e.g. cup).*

Disjunctive Syllogism: The information relevant for success on Known Label trials (e.g. "ball") is to be found in the known target (e.g. ball) and in the label heard (e.g. "ball"). No Disjunctive Syllogism is required. Therefore, participants are faster when they begin their search fixated to the known target (e.g. ball).

- 4) *For Novel Label trials (e.g. "dax") participants are faster to point to the labeled target when they begin their search fixated on the distractor object (e.g. brush) rather than the target object (e.g. phototube).*

Disjunctive Syllogism: The information relevant for success on Novel Label trials (e.g. "dax") is to be found in the distractor object (e.g. brush) and in the label heard (e.g. "dax"). Therefore, participants are faster when they begin their search fixated on the distractor object (e.g. brush).

- 5) *Reaction time to switch gaze away from a fixated object is delayed when either the object (e.g. phototube) or the label (e.g. "dax") is novel (Appendix A).*

Disjunctive Syllogism: Switches in gaze are motivated via the detection of a mismatch between the object fixated (e.g. cup) and the label heard (e.g. "ball") and vary predictably as a function of the number of routes that are available for detecting a mismatch (see Appendix A).

- 6) *Looking and pointing on Novel Label trials (e.g. "dax") is parametrically*

*similar to that observed on Not-Known trials (e.g. "not the iron").*

Disjunctive Syllogism: Not-Known trials (e.g. "the winner is not the iron") and Novel Label trials (e.g. "the winner is the dax") both require participants to work through a Disjunctive Syllogism. Not-Novel trials involve an explicit negation (an explicit Disjunctive Syllogism) while Novel Label trials require the rejection of the known object distractor (e.g. brush) via a word-learning principle (an implicit Disjunctive Syllogism).

- 7) *On Not-Novel trials (e.g. "not the tever") the relative ordering of point times returns to that observed on Known Label trials (e.g. "ball") (i.e. pointing is faster on target-fixated than on distractor-fixated trials), participants have a tendency to triple-check the distractor object on distractor-fixated Not-Novel trials (e.g. looking at tever, hearing "not the tever"), and participants learn the names of novel objects on Not-Novel trials (e.g. "not the tever") as well as they do on Novel trials (e.g. "dax").*

Disjunctive Syllogism: Not-Novel trials (e.g. "not the tever") require participants to first learn what a "tever" is before deciding what a "tever" is not. That is, Not-Novel trials require participants to perform an implicit Disjunctive Syllogism (e.g. "tever") followed by an explicit Disjunctive Syllogism (e.g. not the tever"). Therefore, participants are faster to reject the known object (e.g. bell) when they begin their search fixating this object. Once the known object has been rejected, participants can switch their gaze to the tever, map the novel label to this object, and then reject it via an explicit Disjunctive Syllogism.

- 8) *Normalizing participants' looking on target-fixated Novel Label trials (e.g. looking at phototube, hearing "dax") to the moment of a double-check reveals a pattern of fixation that mirrors that observed on distractor-fixated Novel Label trials (e.g. looking at brush, hearing "dax") (i.e. after the double-check, target-fixated trials become distractor-fixated trials, see Figure 10).*

Disjunctive Syllogism: The rejection of the known object distractor (e.g. brush) is the rate-determining step for mapping a novel label (e.g. "dax") to a novel object (e.g. phototube). Thus, at whatever time after label onset (e.g. "dax") participants happen to shift fixation to the known object distractor (e.g. brush), the looking pattern that follows should be similar.

- 9) *Participants' reaction time to point to the labeled target on Novel Label trials (e.g. "dax") is positively correlated with the word length of the distractor object's known name (e.g. "hat" vs. "flashlight") and not with the visual novelty of this object (e.g. apple vs. artichoke).*

Disjunctive Syllogism: The rejection of known object distractors (e.g. hat or flashlight) requires participants to access the known label for these objects. The shorter this label is, the faster a word-learner will be to retrieve it from memory, reject the known object distractor and motivate the mapping of the novel label (e.g. "dax") to the novel object (e.g. phototube).

- 10) *Adult participants report using a "process-of-elimination" to determine the referent of a novel label (e.g. "dax").*

Disjunctive Syllogism: Adults may have some meta-cognitive awareness of the strategy they are using, though a word-learner need not be an explicit hypothesis-tester in order to perform a Disjunctive Syllogism (i.e. process-of-elimination).

- 11) *The behaviors underlying the successful mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) are identical for children and adults.*

Disjunctive Syllogism: Disjunctive Syllogism underlies the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) in both children and adults.

Of the existing alternatives to the hypothesis that Disjunctive Syllogism underlies the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube), each has difficulty accounting for some subset of the above results.

First, consider the simplest rejoinders to the result that participants double-check the known object distractor before mapping a novel label to a novel object. These include that participants may be double-checking the visual novelty of this object and then motivating the mapping of the novel label (e.g. "dax") to the novel object (e.g. phototube) via a positive motivation to Map-Novelties-to-Novelties. Also, this double-check may be an epiphenomenon caused by a "knee-jerk" reaction to switch gaze after hearing a novel label (e.g. "dax"). While these proposals offer an explanation of the double-checks observed on Novel Label trials (e.g. "dax"), they fail to explain the dependency that follows. That is, these

proposals will have trouble explaining results 4, 6, 8, 9, & 10. Presumably, participants double-check the known object distractor (e.g. brush) to gain information. Results 4, 6 and 8 suggest that the information gained during the double-check determines participants' reaction time to map a novel label to a novel object. These results require that negative evidence (e.g. "'dax' can not refer to the brush") and not a positive motivation to Map-Novelties-to-Novelties drives the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube).

Next, consider a fully specified alternative to Disjunctive Syllogism, i.e. the Competition Model. Merriman (1999) presents a version of MacWhinney's Competition Model (1987) designed to capture word-learners' intuitions about what a novel label might refer to. In this model, all possible referents for a novel label are evaluated and the most novel object wins, where novelty for the model is a function of the number of labels a word-learner knows for the possible referents. That is, the model will choose object for which it knows the fewest labels as the referent of the novel word. This model has much to commend it in its simple design that captures many empirical results, but it faces challenges in light of the present results. Currently, the Competition Model has no way of modeling competition among referents as it unfolds over time. This is because the Competition Model uses the Luce Choice rule to return a categorical measure of the model's choice (Luce, 1963). This problem could be resolved if the use of Luce's Choice rule was replaced by a parallel competition among the possible referents, similar to a "clean-up network" (Hare, Elman, & Daugherty, 1995). Augmenting the Competition Model in this way would place it in the more general category of parallel connectionist models, such as TRACE (McClelland & Elman, 1986), that face challenges given the present results.

A third possible model is suggested by the performance of connectionist models of word recognition such as TRACE (McClelland & Elman, 1986). TRACE has been shown to model participants' patterns of fixations to potential targets that occur as participants attempt to recognize words in continuous speech (e.g. "where is the beaker") (Allopenna, Magnuson, & Tanenhaus, 1998). This work is impressive for the case of known labels (e.g. "ball"). TRACE has not been extended to the case of novel labels (e.g. "dax"). However, such an extension will have difficulties with some of the present results as TRACE does not allow activation in the lexicon to be mediated by the focus of attention, i.e. an interaction between the object fixated and the label heard. As was revealed in results 1, 4, 5, and 8 the mental computations that lead word-learners to map novel labels (e.g. "dax") to novel objects (e.g. phototube) involve an interaction of these two representational formats. As a related challenge, because information in TRACE is allowed to combine in parallel, it will

have difficulty explaining the serial character that is revealed in the interaction of the type of label (e.g. known, novel) and the object fixated at the time of label onset (e.g. target, distractor). This includes results 2, 3, and 4.

A final challenge to connectionist models, the competition model, and probabilistic models in general is presented by the explicit negations used in Experiment 2. These models have not presented a non-symbolic treatment of explicit negation (e.g. "not the iron") (Halberda; in preparation). Therefore, such models will have difficulty explaining the agreement between Novel Label trials (e.g. "dax") and Not-Known trials (e.g. "not the iron"). For this same reason, parallel models do not make a clear prediction about participants' performance on the Not-Novels trials of Experiment 2 (e.g. "not the tever").

Indeed, the challenge of a proper treatment of explicit negation (e.g. "not the iron") is perhaps the most far-reaching concern raised by the present studies. In Experiment 2, the pattern of results on Novel Label trials (e.g. "the winner is the dax") was parametrically matched to results on Not-Known trials (e.g. "the winner is not the iron"). Pragmatically, the negation involved on Not-Known trials (e.g. not the iron) was a contradictory or logical negation. Contradictory negation is any negation that is governed by the Law of Contradiction (LC) and the Law of Excluded Middle (LEM). The 'winner'-task from Experiment 2, participants were told that there would be one object that was the winner and one that was the loser on each trial. Thus, on a trial such as "the winner is not the iron", the iron must either be the winner or the loser (i.e. LEM) and the iron could not be both the winner and the loser at the same time (i.e. LC). Since Aristotle, contradictory negation has been argued to require a symbolic account of its meaning (see Horn, 1989/2001 for extensive review). Even the leading alternative to mental logic, the Mental Models account, recognizes that a non-symbolic treatment of logical negation is impossible (Johnson-Laird, 2002). For this reason, contradictory negation is unlikely to be amenable to the non-propositional statistical treatments of connectionist networks. Such a challenge would also be faced by Bayes nets (i.e. provided that the Bayes versions do not include a symbol for logical negation). In order to describe the parametric agreement of Novel (e.g. "dax") and Not-Known trials (e.g. "not the iron"), such models will require some added stipulation that operates outside of the bounds of the models themselves<sup>6</sup>.

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<sup>6</sup> One amendment to the existing literature on mental models that is motivated by the present results is that, perhaps, when negation functions to remove an existing model from consideration (e.g. A or B, not A, Therefore B), the model is brought into the focus of attention (i.e. Not-A) in order to remove it.

In the present article I have considered word-learners' tendency to map novel labels (e.g. "dax") to novel objects (e.g. phototube) in cases of referential ambiguity. Using a detailed analysis of participants' looking-time within a trial and their reaction time to point to both known and novel targets (e.g. ball and phototube), I have offered an analysis of the mental computations that support the use of this strategy. That these computations may take the form of logical deductive inferences opens the possibility of an intersection of the study of word-learning and logical reasoning that will be explored in future work. These results also offer a promising look at the information that can be gained through using continuous rather than categorical measures of success in developmental studies. Such measures may form a bridge between classical work in cognitive development and current efforts in computational modeling.

## Appendix A

What are the processes that allow word-learners to reject an object as a possible referent of a novel or known label? Experiment 3 suggested that retrieval of a known object's familiar label (e.g. "brush") plays a necessary role in the processes that allow participants to reject a known object (e.g. brush) as a possible referent of a novel label (e.g. "dax"). In Experiment 3, the word length of the known object's familiar label (e.g. "hat" vs. "flashlight") was positively correlated with participants' reaction time to map a novel label (e.g. "dax") to a novel object (e.g. phototube). This effect suggests that word-learners are retrieving the known object's familiar label (e.g. "hat") in order to reject the object as a possible referent of the novel label (e.g. "dax"). The longer the known label (e.g. "flashlight"), the longer it took to reject the known object.

Other trial types may also require a rejection of the object being fixated. Consider cases where participants happened to be fixating the known object distractor (e.g. cup) on Known Label trials (e.g. "ball"). Here too, participants must reject the known object distractor (e.g. cup) as a possible referent of the known label (e.g. "ball") in order to motivate the shift in gaze that will bring the correct referent (i.e. ball) into the focus of attention. For this reason, an analysis of participants' reaction times to switch gaze on the various trial types may offer evidence as to the representations and processes involved in the rejection of known and novel objects.

Recent work from Swingley and colleagues (Fernald, Swingley & Pinto, 2001; Swingley & Fernald, 2002) demonstrates that what motivates participants to switch gaze away from an incorrect



object (e.g. looking at cup, hearing "ball") is a rejection of the fixated object (i.e. cup) and not any positive motivation to switch gaze towards the correct object (i.e. ball). That is, even when participants know where the "correct" object is located (i.e. ball), the representations involved in their motivation to switch gaze away from an incorrect object originate in the object fixated (i.e. cup) and the label heard (i.e. "ball").

The motivation to switch gaze involves the detection of a mismatch between the object fixated (e.g. cup) and the label heard (e.g. "ball"). In order for a cognitive system to register such a mismatch, participants must come to represent the two individuals (object:cup and label:"ball") within a common format.

In considering the case of a Distractor-Fixated Known Label trial (looking at cup, hearing "ball"), there are two possible routes for detecting a mismatch. Participants may retrieve the known label for the fixated object (i.e. label:"cup") and recognize that this label does not match what is heard in the speech stream (i.e. label:"cup" label:"ball"). This would motivate participants to switch gaze away from the cup. As a second route, participants may retrieve an imagistic representation of the labeled object (i.e. object:ball) and recognize that this image does not match the fixated object (i.e. object:ball object:cup). This would also motivate participants to switch gaze away from the cup. A simple prediction is that whenever one of these routes is blocked (by novelty in the label or in the object), participants should take longer to detect a mismatch. Two routes are better than one.

Another treatment that leads to the same prediction is that participants may contact an abstract, amodal, representation for each individual (i.e. BALL and CUP). It may be that the modality-specific representations (i.e. label:"ball" and object:cup) are simply connections which allow access to these abstract representations. While the distinction between modal and amodal representations is an important one, the effects which concern me here would follow from either account (*for review and discussion see Markman A. & Dietrich, 2000; for an argument that some representations must be amodal see Johnson-Laird, 2002*). That is, whether object:cup and label:"ball" are considered representations that are themselves fit for comparison, or whether they are considered routes to accessing abstract representations, the number of possible routes to finding a mismatch should affect participants' reaction time to detect a mismatch. For ease and clarity, I will continue to use the modal representations e.g. label:"ball" and object:cup.

In attempting to specify the processes involved in the rejection of "wrong" objects as possible referents of a heard label, the present analysis asks: Does the number of possible routes to detecting a mismatch predict participants' reaction time to reject

a fixated object (i.e. switch gaze)? An analysis of participants' reaction times to switch gaze on the various trial types from Experiments 1 (adults) and 4 (preschoolers) follows.

Consider cases where subjects switch gaze away from the object they are fixating at the time of label onset on the various trial types. These are cases where participants have discovered a mismatch between the object fixated and the label heard. The reaction time to switch gaze on such trials (i.e. from label onset to the initiation of a switch) may serve as a measure of the processing time involved in detecting a mismatch. This processing time should vary as a function of the number of possible routes for detecting a mismatch.

In Table 3, the mean reaction time for the relevant trial types from Experiments 1 and 4 is summarized, constructed from subject means.

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As shown in Table 3, there are two possible routes to detecting a mismatch. On Distractor-Fixated Known Label trials with a known distractor (looking at cup, hearing "ball") participants might retrieve an imagistic representation for the referent of this known label (e.g. object:ball), compare it to the object fixated (e.g. cup) and notice a mismatch (i.e. object:ball object:cup). Alternatively, participants might retrieve the known label for the object fixated (e.g. label:"cup"), compare it to the label heard in the speech stream (e.g. "ball") and thereby notice a mismatch (i.e. label:"cup" label:"ball"). On Distractor-Fixated Known Label trials with a known distractor (looking at cup, hearing "ball") it took preschoolers 445 msec to reject the fixated object (e.g. cup) as a possible referent of the known label (e.g. "ball") and initiate a switch in gaze. Also displayed in Table 3, it took adults on average 330 msec to perform an identical rejection (note: Experiments 1 and 4 were identical with the exception of giving preschoolers an additional 250 msec to respond).

Compare these reaction times to those observed when participants happened to be fixating a novel object (e.g. phototube) when hearing a known label (e.g. "brush") (i.e. Distractor-Fixated Known Label trials with a novel distractor) (note: participants succeeded on both of these Known Label trial types, and these trials were collapsed throughout earlier analyses. But here their subtle differences are of interest). When fixating a novel object (e.g. phototube) and hearing a known label (e.g. "brush") there is only one route to detecting a mismatch. Participants must retrieve an imagistic representation for the referent of the known label (e.g. object-brush)

and compare this to the fixated object (e.g. phototube) in order to detect the mismatch which motivates a switch in gaze (e.g. object-brush → object-phototube). Participants cannot access a known label for the novel object (e.g. phototube = "dax") in order to compare it to the known label (e.g. "brush"), as the novel object (e.g. phototube) was constructed in the lab and had no known label. Reaction times to switch gaze on Distractor-Fixated Known Label trials with a Novel Distractor (looking at phototube, hearing "brush") should be longer than reaction times on Distractor-Fixated Known Label trials with a Known Distractor (looking at cup, hearing "ball"). This is the pattern seen in Table 3. For both preschoolers and adults, the latency to switch gaze on Distractor-Fixated Known Label trials with a Novel Distractor (looking at phototube, hearing "ball") (e.g. 408 msec) is longer than that on Distractor-Fixated Known Label trials with a Known Distractor (looking at cup, hearing "ball") (e.g. 330 msec) as revealed by paired-samples t-tests: Table 3 comparison a, preschoolers,  $t(18) = -1.77, p = .093$ , adults,  $t(19) = -2.96, p < 0.01$ .

Word-learners also have access to only one route on Distractor-Fixated Novel Label trials (looking at brush, hearing "dax"). As is shown in Table 3, on these trials participants must retrieve the known label for the fixated object (e.g. label-"brush") and compare this to the label heard in the speech stream (e.g. "dax") in order to detect the mismatch which motivates a switch in gaze (e.g. label-"brush" label-"dax"). Participants cannot access an imagistic representation in memory for the referent of a novel label (e.g. "dax" = phototube) as these labels had no known referent in English. Reaction times to switch gaze on Distractor-Fixated Novel Label trials (looking at brush, hearing "dax") should be longer than reaction times on Distractor-Fixated Known Label trials with a Known Distractor (looking at cup, hearing "ball"). This is the pattern seen in Table 3. For both preschoolers and adults, the latency to switch gaze on Distractor-Fixated Novel Label trials (looking at brush, hearing "dax") (e.g. 442 msec) is longer than that on Distractor-Fixated Known Label trials with a Known Distractor (looking at cup, hearing "ball") (330 msec) as revealed by paired-samples t-tests: Table 3 comparison b, preschoolers,  $t(19) = -1.53, p = .142$ , adults,  $t(18) = -2.36, p < .05$ .

On Target-Fixated Novel Label trials (looking at phototube, hearing "dax") participants are in a different situation. As summarized in Table 3, neither the label route nor the image route will allow participants to detect a mismatch on these trials. The novel label (e.g. "dax") has no known imagistic representation that might be retrieved. The novel object (e.g. phototube) has no known label that participants might access.

It seems likely that participants fail to reach a threshold for recognition of either the name of the novel object (e.g. phototube) or an imagistic

representation for the novel label (e.g. "dax"). Participants must wait for processing to return a null result, i.e. failure to retrieve a known basic-level kind mapping in memory for the object (e.g. phototube) and for the label (e.g. "dax"), before they can be certain that these individuals are in fact novel. For this reason, reaction time to switch gaze on Target-Fixated Novel Label trials (looking at phototube, hearing "dax") should be longer than on any other trial type. An exhaustive search of the lexicon, or a failure to attain recognition-threshold will take longer than the retrieval of a known mapping (e.g. ball = "ball").

This pattern is suggested in Table 3. For both preschoolers and adults, the latency to switch gaze on Target-Fixated Novel Label trials (looking at phototube, hearing "dax") (e.g. 539 msec) is longer than on any other trial type, though this trend often failed to reach significance: compared to Known trials with Known distractor, preschoolers  $t(16) = -2.44, p < .05$ , adults  $t(17) = -2.14, p < .05$ , compared to Known trials with Novel distractor, preschoolers  $t(15) = -1.18, p = .258$ , adults  $t(17) = -1.59, p = .129$ , compared to Distractor-Fixated Novel trials, preschoolers  $t(16) = -1.20, p = .246$ , adults  $t(15) = -1.02, p = .325$ .

Thus, an analysis of participants' reaction time to switch gaze away from a fixated object reveals that: 1) a switch in gaze is motivated by the detection of a mismatch between the object fixated (e.g. cup) and the label heard (e.g. "ball"), 2) in order to detect this mismatch participants must come to represent these two individuals (i.e. object and label) in a common format, and 3) the number of routes to detecting a mismatch affects the processing time required

## Appendix B

While Experiments 1-4 support the hypothesis that Disjunctive Syllogism and not Map-Novelty-to-Novelty underlies word-learners' mapping of novel labels to novel objects, some integration of these two proposals may be required. An analysis of preschoolers' reaction time to point on Novel and Known Label trials reveals that, after rejecting the familiar object distractor (e.g. brush), children check the novelty of the novel object (e.g. phototube) before completing the mapping a novel label (e.g. "dax") to the novel object (e.g. phototube). If Disjunctive Syllogism were the only computation involved in making this mapping then such a check for novelty would not be required. Thus, while it is clear that explicit rejection of known object distractors (e.g. brush) plays a causal role in motivating the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube), the spirit of Map-Novelty-to-Novelty may be preserved in this check for novelty that precedes the mapping of novel labels to novel objects.

To confirm that preschoolers evaluate the novelty of the novel object (e.g. phototube) after having rejected the familiar object distractor (e.g. brush), preschoolers' reaction time to point was normalized to the switch in gaze that marks the rejection of the known object distractor (e.g. brush) on distractor-fixated Novel Label trials (looking at brush, hearing "dax"). This normalized point time was compared to normalized point times from two other trial types, displayed in Table 4.

Because rejection of a fixated object varies as a function of the number of routes available for detecting a mismatch (see Appendix A,) it is important to normalize point times to the completion of this rejection before making comparisons between trial types. Looking for the three trial types was modeled using exponential rate equations, displayed in Figure 16, and pointing was normalized to the moment at which looking attained 80% of the asymptote for each trial type.

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For Distractor-Fixated Known Label trials with a known distractor (looking at cup, hearing "ball") and Distractor-Fixated Known Label trials with a novel distractor (looking at phototube, hearing "brush"), normalized reaction time to point to the labeled target did not differ as measured by paired-samples t-test: Table 4 comparison a,  $t(15) = 0.97$ ,  $p = 0.347$ . This illustrates that, once the distractor object has been rejected (known or novel), there is no difference in the time required to evaluate the known target (e.g. ball or brush) and point to it.

Paired-samples t-tests revealed that the normalized reaction time to point on Distractor-Fixated Novel Label trials (looking at brush, hearing "dax") was significantly longer than reaction time on each of the Known Label trial types: compared to Distractor-Fixated Known Label trials with a known distractor (Table 4 comparison b),  $t(17) = 5.68$ ,  $p < 0.001$ , compared to Distractor-Fixated Known Label trials with a novel distractor (Table 4 comparison c),  $t(15) = 2.94$ ,  $p < 0.01$ . This suggests that after preschoolers have rejected the known object distractor (e.g. brush) and shifted gaze to the novel object (e.g. phototube), they evaluate whether or not the novel

object is in fact novel before mapping the novel label (e.g. "dax") to the novel object. This evaluation was not required on Known Label trials. Though preschoolers certainly evaluated whether or not the labeled target (e.g. ball) was in fact a ball, I showed in Table 3 that this evaluation takes significantly less time than an evaluation of the novelty of the target object (e.g. phototube)).

Thus, even after having rejected known objects (e.g. brush) as possible referents of a novel label (e.g. "dax"), children evaluate whether or not the target object (e.g. phototube) is in fact novel before deciding to map the novel label (e.g. "dax") to the novel object (e.g. phototube). This desire to map novel labels to novel objects preserves the role played by constraints such as N3C. While the results of Experiments 2-4 show that rejection of known object distractors (e.g. brush) is the rate-determining step for motivating the mapping of novel labels (e.g. "dax") to novel objects (e.g. phototube) (i.e. Disjunctive Syllogism), children also honor the principle of N3C (i.e. Map-Noveltly-to-Noveltly) as they ensure that the target object (e.g. phototube) is in fact novel before completing this mapping.

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Table 1

Known and Novel Labels Used in Experiment 1

	Known Labels (Distractor)		Novel Labels (Distractor)
ax (bat)	clock (ruler)	pencil (fork)	blick (scissors)
bed (pan)	door (cup)	pipe (violin)	chatten (flashlight)
bell (novel)	glasses (pepper)	snail (novel)	dax (kite)
belt (novel)	iron (pumpkin)	trumpet (novel)	krat (guitar)
car (spoon)	knife (stool)	umbrella (basket)	lorp (hat)
chair (novel)	pen (bicycle)	wagon (novel)	pizer (desk)

Table 2





Predicted Computations and Observed Switches in Gaze for Experiment 2

Trial Type	Object Fixated at Label Onset	Predicted # of Computations	Observed Switches in Gaze (SE)	Observed Point Time msec (SE)
Known	target	0	0.65 (0.2)	1134 (59)
	distractor	1	1 (0)	1332 (58)
Not-Known	target	2	1.82 (0.1)	1439 (82)
	distractor	1	1 (0)	1218 (58)
Novel	target	2	1.94 (0.1)	1953 (70)
	distractor	1	1.46 (0.26)	1829 (94)
Not-Novel	target	2	1.8 (0.2)	2123 (218)
	distractor	3	1.67 (0.3)	2326 (257)



Table 3

Detecting a Mismatch and Latency to Switch Gaze

Trial Type	Object Fixated	Label Heard	Mismatch in:		Latency to Switch Gaze msec (SE)	
			Image	Label	Preschoolers (Exp. 4)	Adults (Exp. 1)
Distractor-Fixated Known Label trials (w/ known object distractor)		"ball"	✓	✓	445 (26)	330 (32)
Distractor-Fixated Known Label trials (w/ novel object distractor)		"brush"	✓		521 (46)	408 (34)
Distractor-Fixated Novel Label trials		"dax"		✓	532 (48)	442 (55)
Target-Fixated Novel Label trials		"dax"			675 (94)	539 (94)

a

b

Footnote: The means displayed in Table 3 included only those trials on which participants switched gaze before trial offset to ensure an accurate measure of the time required for making a rejection.

Table 4

Latency to Point Following Rejection of the Distractor




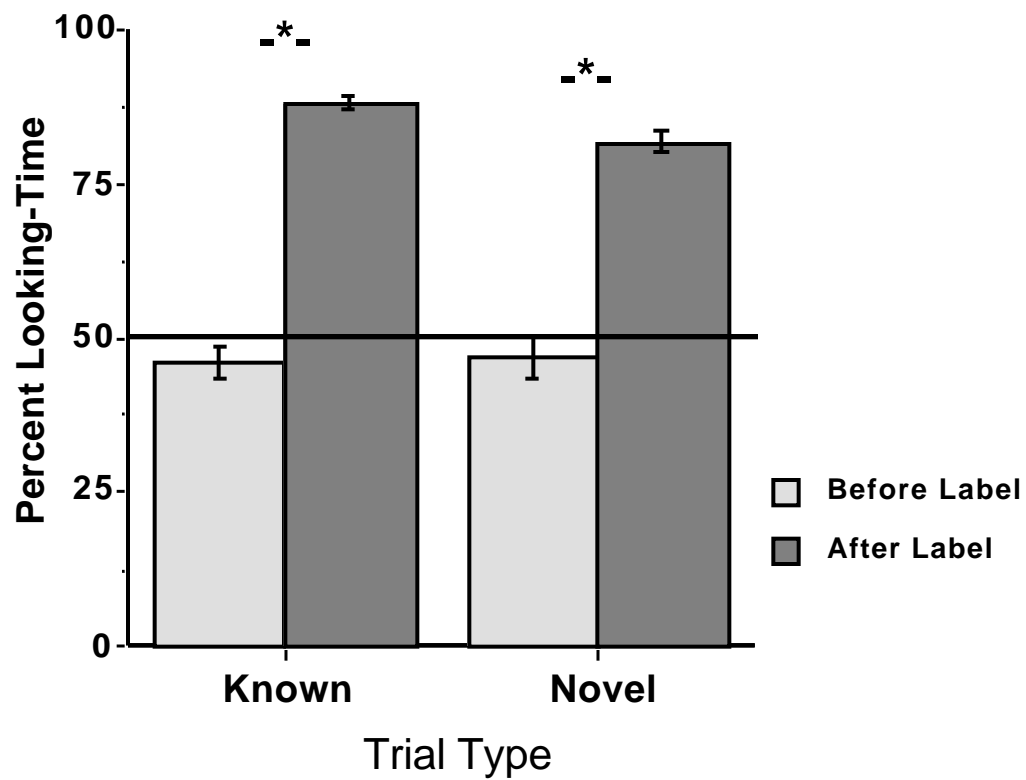
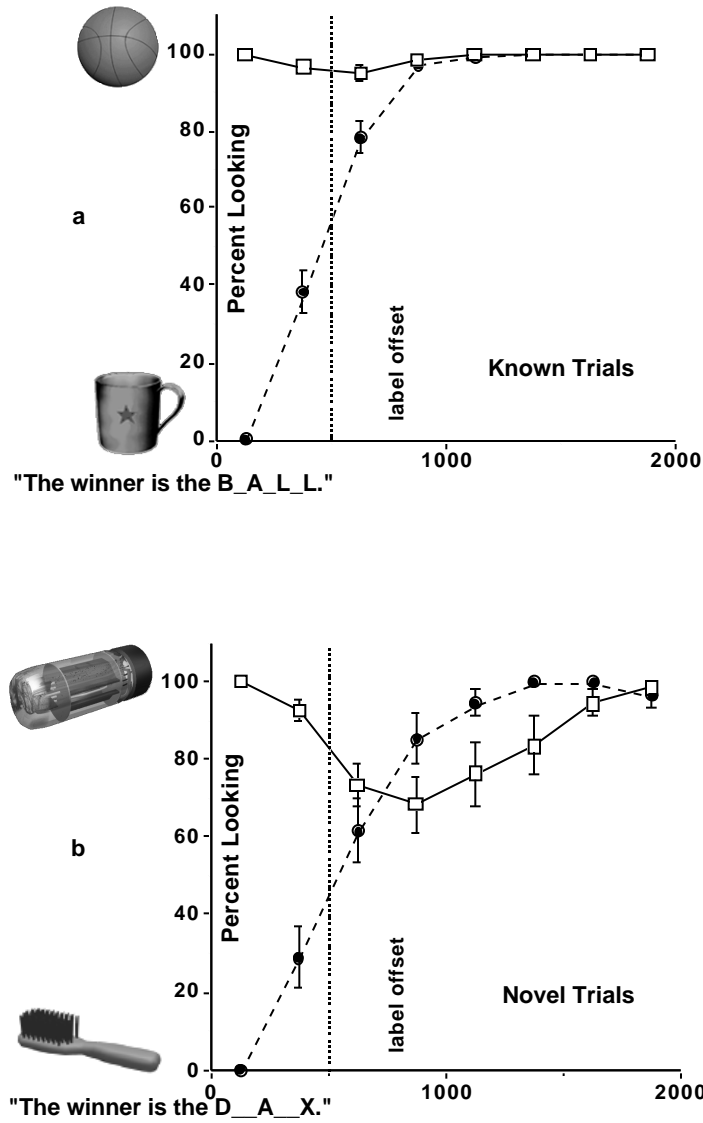
Trial Type	Object Fixated	Label Heard	Mismatch in:		Latency to Point After Switching Gaze msec (SE)	Preschoolers (Exp. 4)
			Image	Label		
Distractor-Fixated Known Label trials (w/ known object distractor)		"ball"	✓	✓	711 (35)	<div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <div style="border-left: 1px solid black; height: 100px; position: relative;"> <div style="position: absolute; top: 0; right: -10px;">a</div> <div style="position: absolute; bottom: 0; right: -10px;">c</div> </div> <div style="position: absolute; right: -10px; top: 50%; transform: translateY(-50%);">b</div> </div> </div>
Distractor-Fixated Known Label trials (w/ novel object distractor)		"brush"	✓		795 (104)	
Distractor-Fixated Novel Label trials		"dax"		✓	1094 (73)	



Figure 1. A novel object used in Experiment 1. All objects were presented in color.



**Figure 2.** Percent-looking to the target object before and after label onset in Experiment 1. Percent-looking is equal to the time spent looking at the target, divided by the time spent looking at either object times 100. Thus, chance looking is 50%. The significant increase in percent looking following label onset indicates that adults succeeded on both Known and Novel Label trials.



**Figure 3.** Percent-looking to the target object is displayed for trials on which participants happened to be fixating either the target (open boxes) or distractor (filled circles) at time of label onset in Experiment 1. Percent-looking is displayed for both Known and Novel Label trials from the time of label onset (0 msec) to trial offset (2000 msec). Frame-by-Frame graphs are constructed from subject means and thus each subject contributes equally to the observed pattern of looking. That adults double-check the known object distractor (e.g. brush) on Target-Fixated Novel Label trials (looking at phototube, hearing "dax") (3b) is consistent with the computational structure of Disjunctive Syllogism (i.e. "Dax" either refers to the brush or to the novel object. 'Dax' can not refer to the brush, therefore 'dax' must refer to the novel object.").

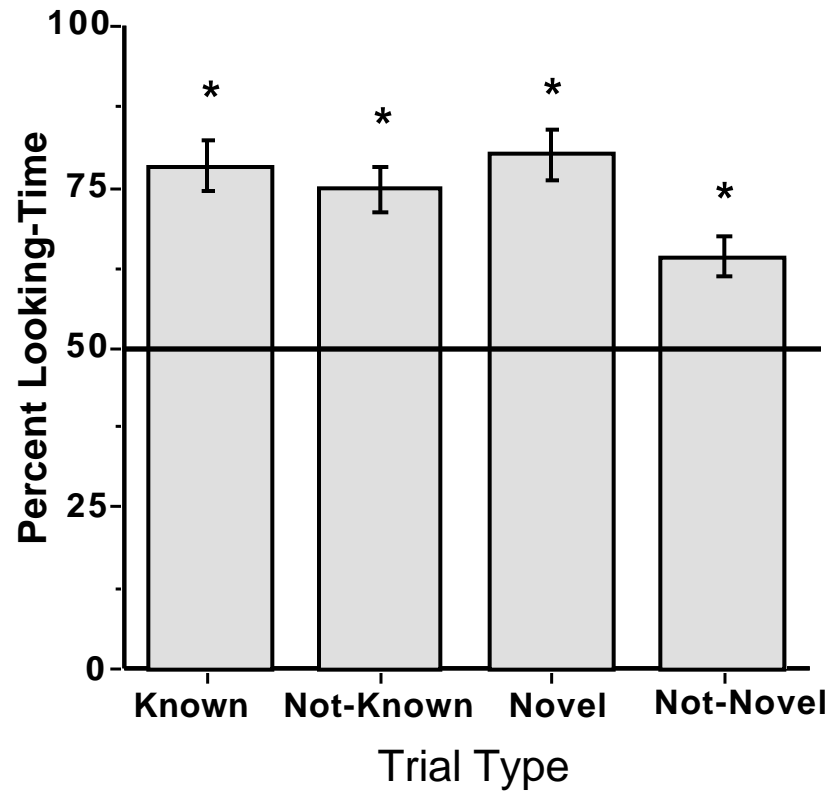
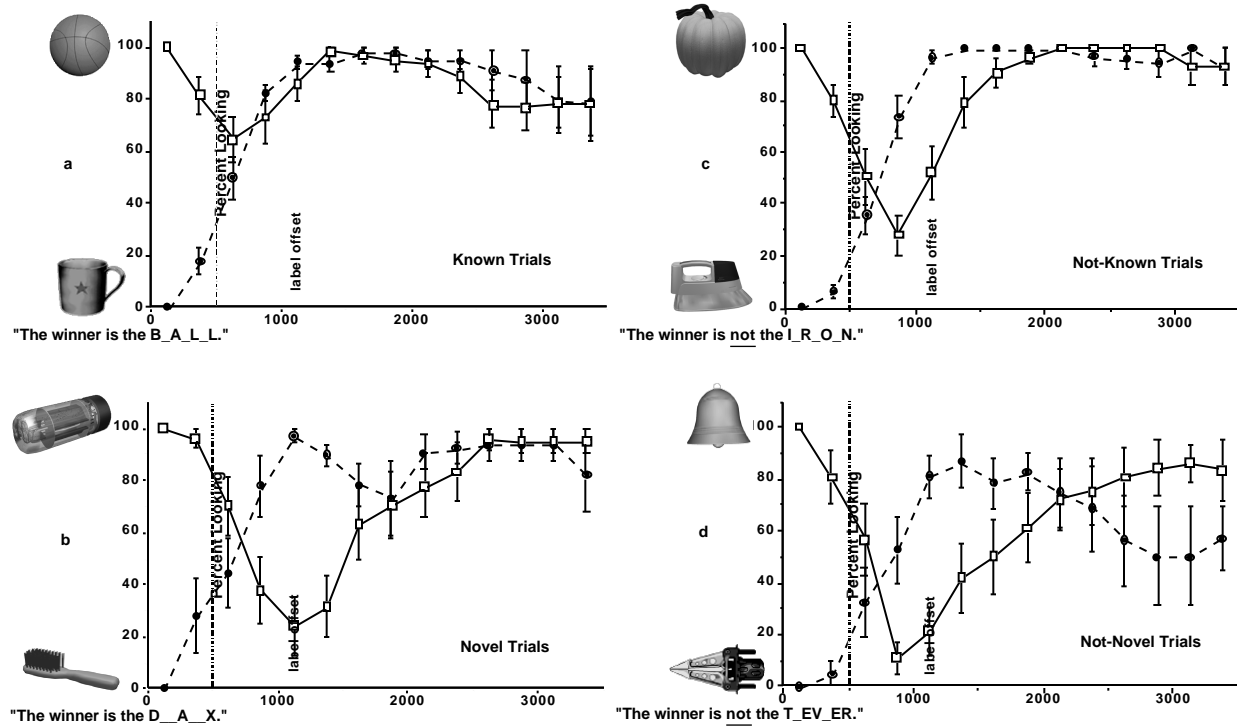


Figure 4. Percent-looking ( $\pm$  SE) to the target object after label onset is displayed for four Trial Types in Experiment 2 (chance = 50%). Adults succeeded on all trial types.



**Figure 5.** Percent-looking ( $\pm$  SE) to the target object is displayed for trials on which participants happened to be fixating either the target (open-boxes) or distractor (filled-circles) at time of label onset in Experiment 2. Percent-looking is displayed for Known (5a), Novel (5b), Not-Known (5c), and Not-Novels trials (5d) from the time of label onset (0 msec) to trial offset (3500 msec). The pattern of eye-movements observed on Novel trials ("the winner is the dax") is parametrically matched to the pattern observed on Not-Known trials ("the winner is not the iron"), as predicted by Disjunctive Syllogism.

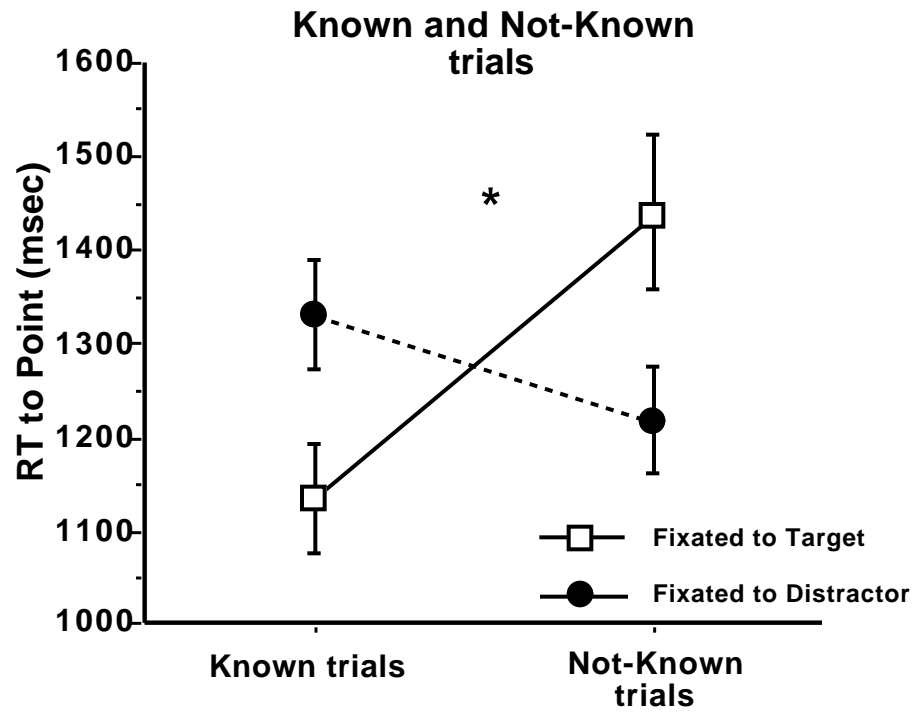


Figure 6. Mean time to point to the target object ( $\pm$  SE) is displayed for Known ("ball") and Not-Known ("not the iron") trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, the interaction is significant  $p < .005$ .



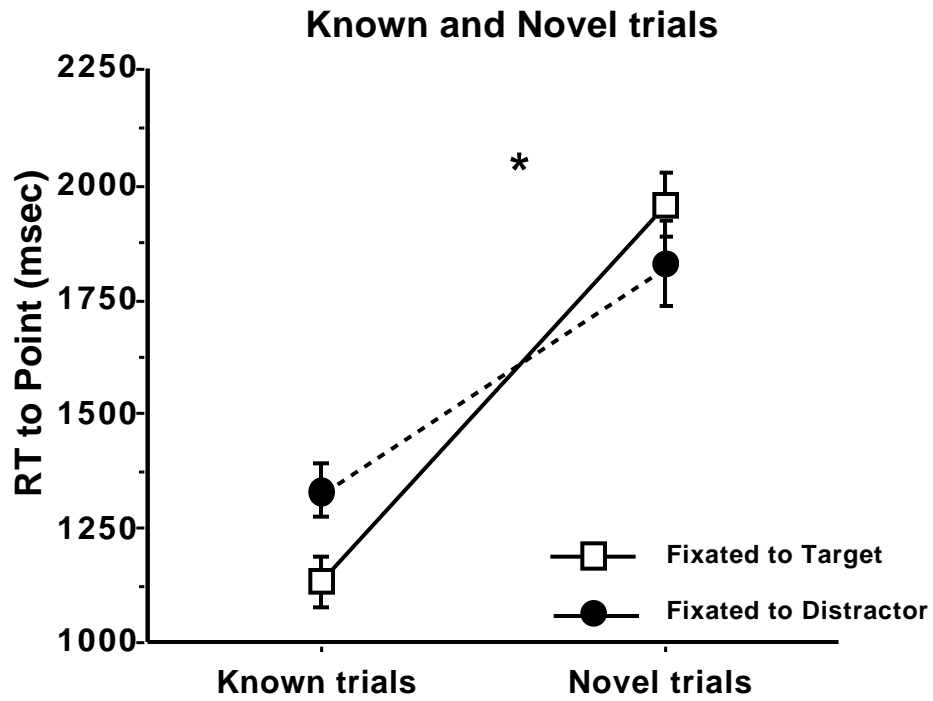


Figure 7. Mean time to point at the target object ( $\pm$  SE) is displayed for Known ("ball") and Novel ("dax") trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, the interaction is significant  $p < .01$ .

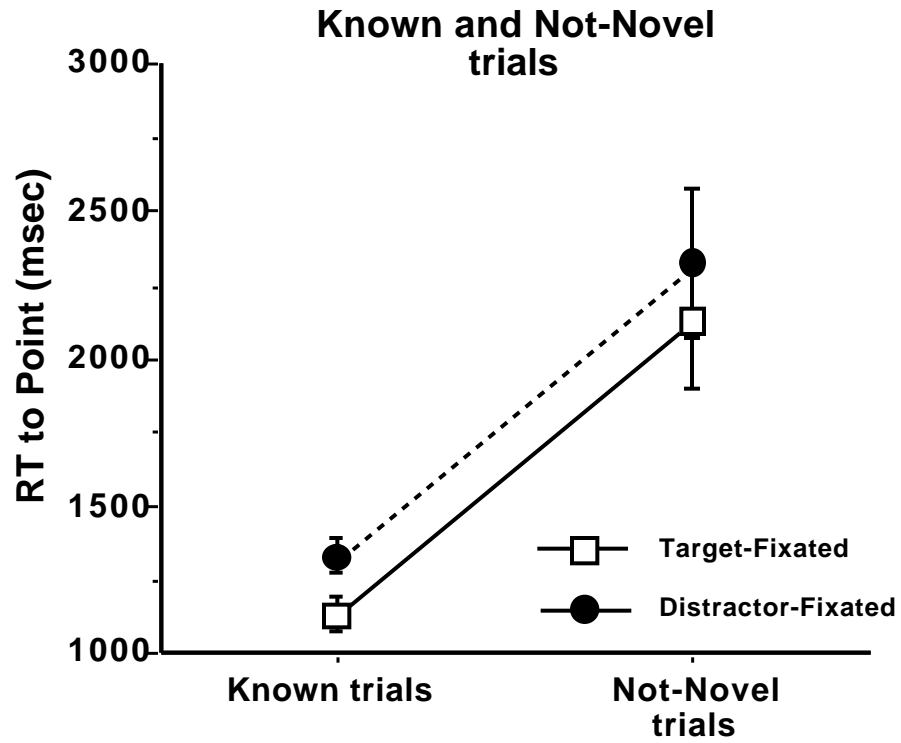


Figure 8. Mean time to point at the target object ( $\pm$  SE) is displayed for Known ("ball") and Not-Novel ("not the tever") trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, there is no interaction.

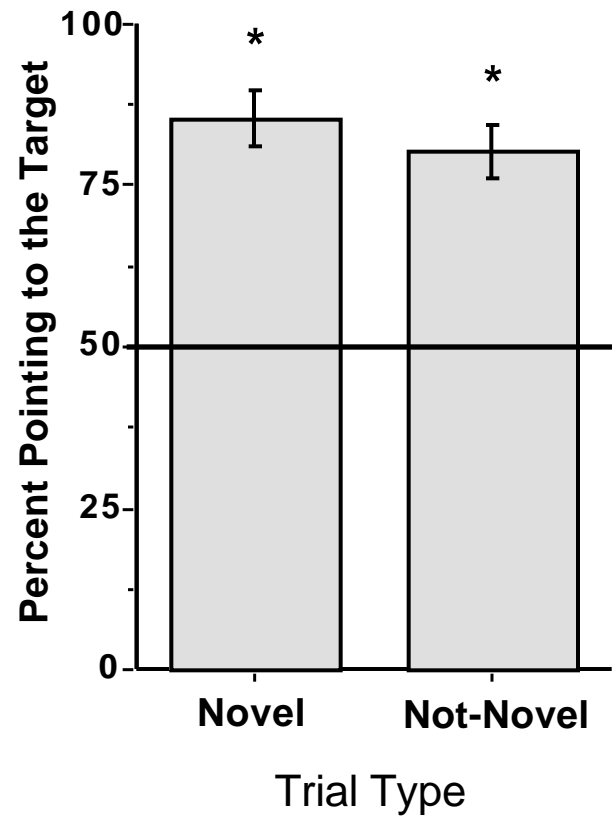


Figure 9. The percentage of trials on which participants correctly identified the target object on post-test trials in Experiment 2 Post-test trials ( $\pm$  SE). Participants successfully learned the novel labels ("dax," "tever" etc.) on both Novel ("the winner is the dax") and Not-Novel trials ("the winner is not the tever"). This supports an implicit-then-explicit Disjunctive Syllogism model by which participants first learned the novel label (e.g. "tever") before reasoning over explicit negation (e.g. "not the tever").

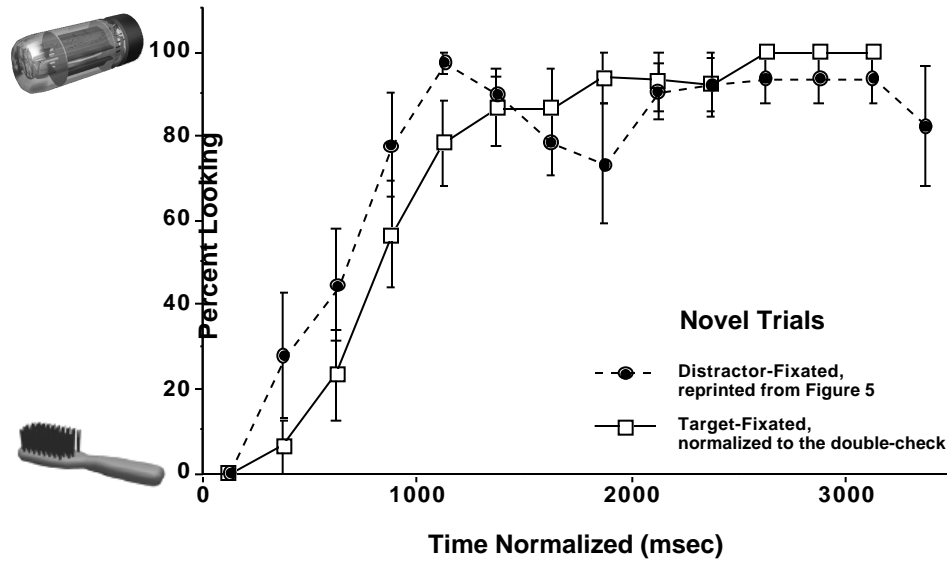


Figure 10. Percent looking is displayed for distractor- and target-fixated Novel Label trials in Experiment 2. For target-fixated trials, looking time has been normalized to the moment at which participants had shifted gaze back to the known object (e.g. brush) during a double-check. The similarity of the resulting curves suggests that information about the known object distractor (e.g. brush) is the rate-determining information for motivating the mapping of a novel label (e.g. "dax") to a novel object (e.g. phototube).

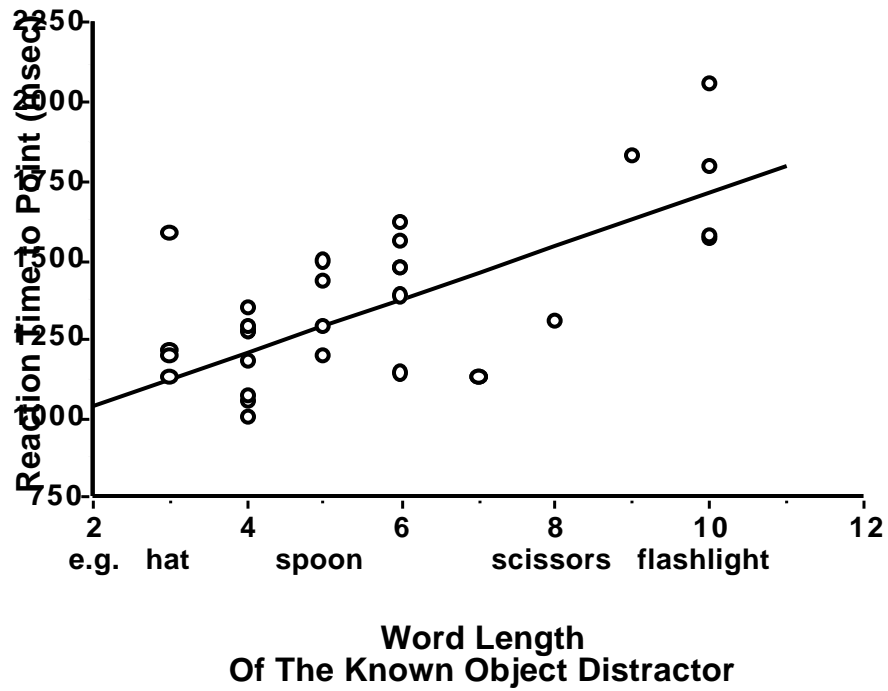


Figure 11. Participants reaction time to point to the novel target object (e.g. phototube) on Novel Label trials (e.g. "dax") in Experiment 3 is displayed as a function of the word length of the name of the known object distractor (e.g. "hat"). The regression is significant,  $p < .005$ , suggesting that retrieval of this label (e.g. "hat") plays a causal role in the rejection of the known object distractor (e.g. hat).

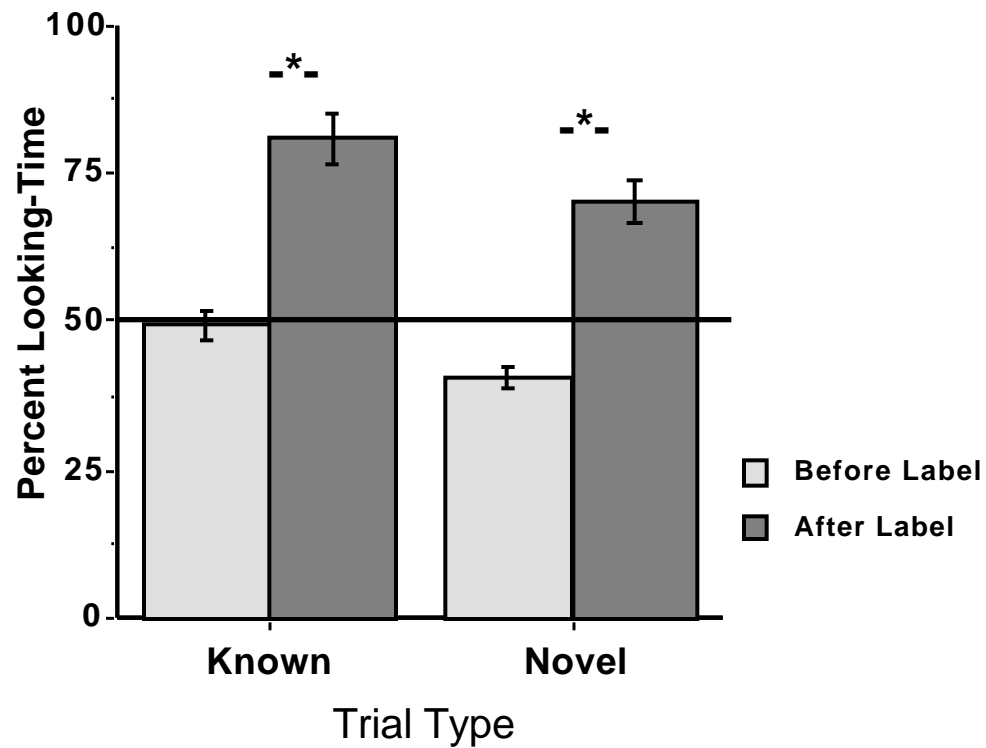
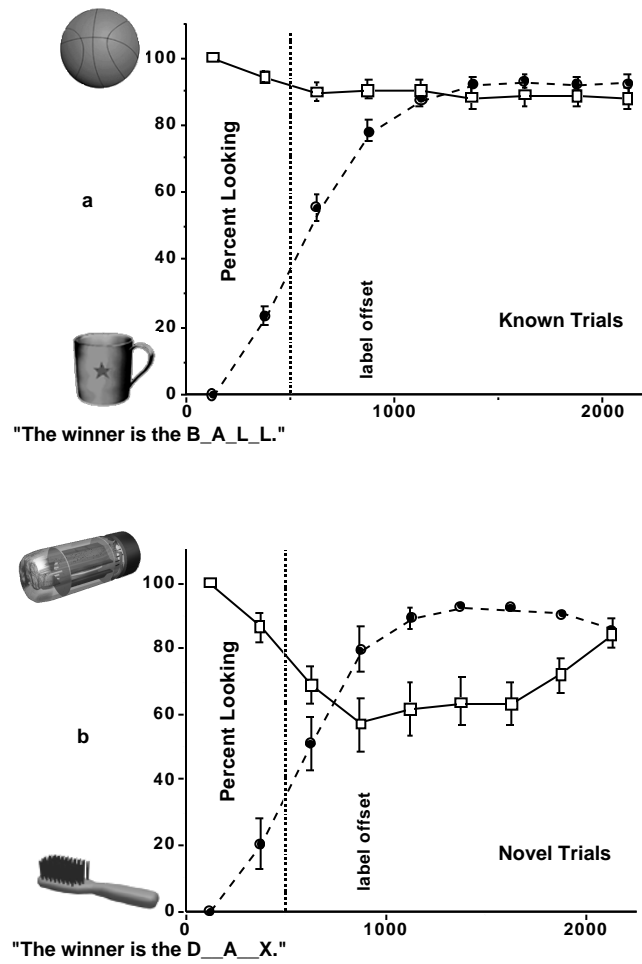


Figure 12. Percent-looking to the target object both before and after label onset in Experiment 4. Percent-looking is equal to the time spent looking at the target, divided by the time spent looking at either object times 100. Thus, chance looking is 50%. The significant increase in percent looking after label onset indicates that preschoolers succeeded on both Known ("ball") and Novel Label trials ("dax").



**Figure 13.** Percent-looking ( $\pm$  SE) to the target object is displayed for trials on which subjects happened to be fixating either the target (open-boxes) or distractor (filled-circles) at the time of label onset in Experiment 4. Percent-looking is displayed for both Known and Novel Label trials from the time of label onset (0 msec) to trial offset (2250 msec). Preschoolers had a significant increase in double-checks of the distractor object (e.g. brush) on Novel (e.g. "dax") compared to Known Label trials (e.g. "ball") as predicted by Disjunctive Syllogism.

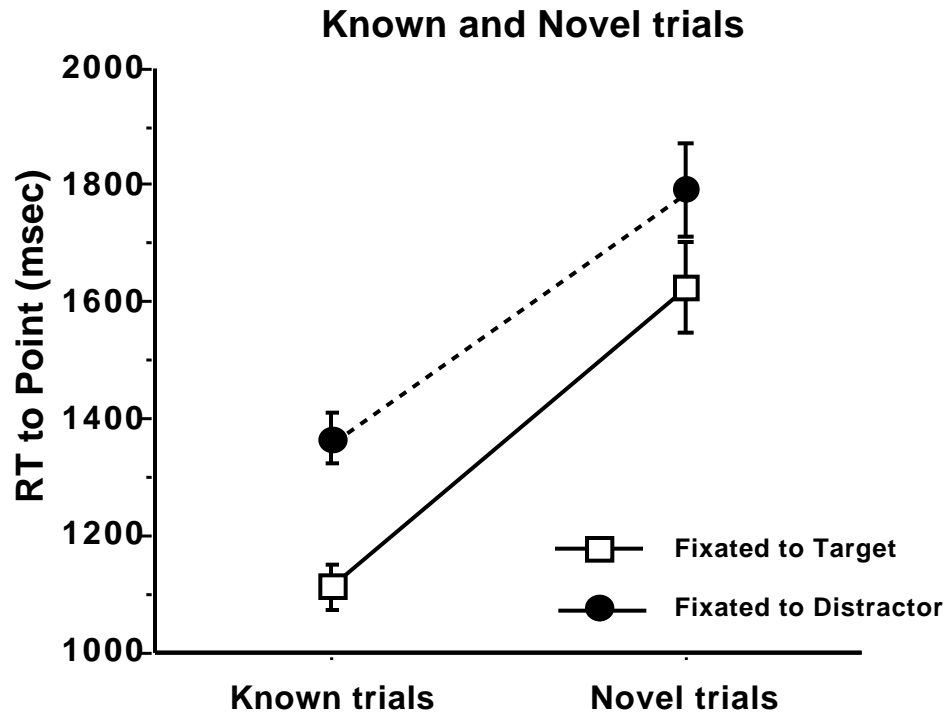
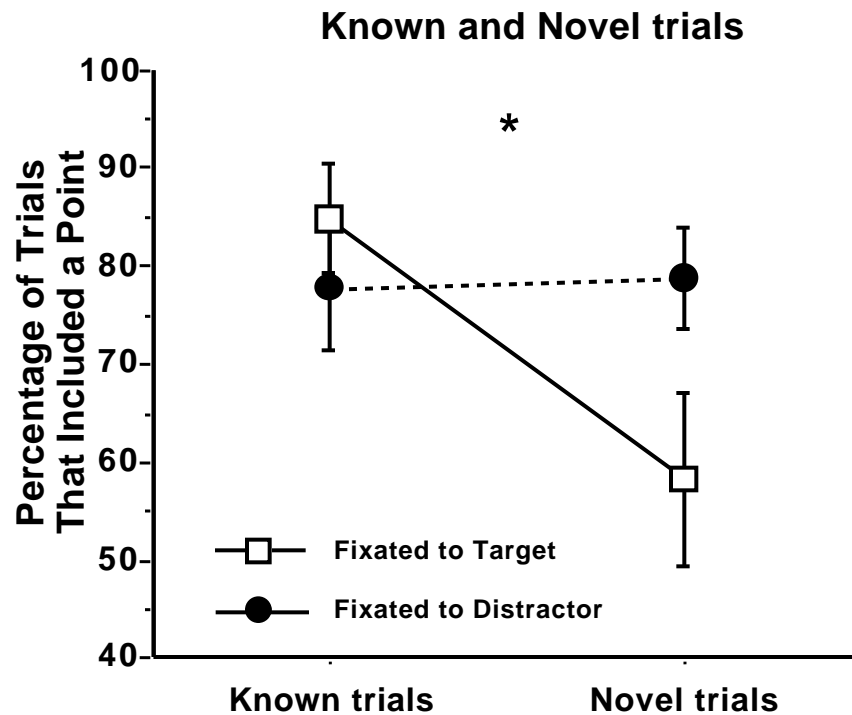


Figure 14. Preschoolers' reaction time to point to the target object is displayed for Known and Novel Label trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 4. The predicted interaction failed to reach significance because trial length was unfortunately too short and artificially selected for points that occurred early on Target-Fixated Novel Label trials (looking at phototube, hearing "dax").





**Figure 15.** The percentage of trials on which preschoolers' successfully pointed to the target object before trial offset is displayed for Known and Novel trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 4. Preschoolers made significantly fewer points to the target object on Target-Fixated Novel Label trials (looking at phototube, hearing "dax") compared to all other trial types. That preschoolers did not have enough time to point on Target-Fixated Novel Label trials (looking at phototube, hearing "dax") supports the predictions of Disjunctive Syllogism. Disjunctive Syllogism predicts that reaction time to point should be longest on these trials.

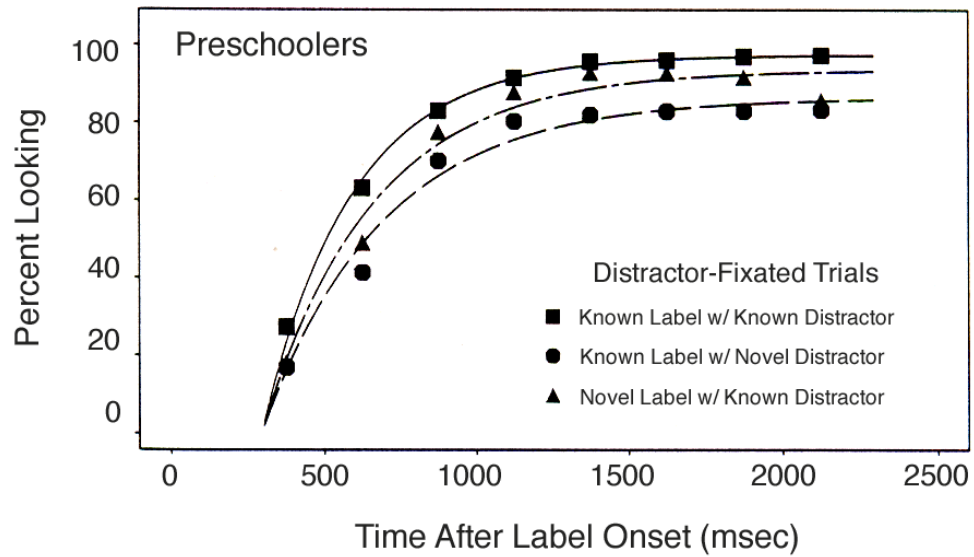


Figure 16. Percent looking for three different trial types from Experiment 4 is displayed along with fitted curves. These curves were modeled using an exponential rate equation:  $[1 - e^{-b(t-t_0)}] = \text{probability}$ , where  $\text{asymptote}$  = asymptote,  $b$  = rate to attain asymptote,  $t_0$  = intercept, and  $t$  = time after label onset. Point times for these three trial types were normalized to the time at which percent looking attained 80% of the asymptotic level. This normalization allows an analysis of the reaction time to point to the target object (e.g. phototube) across trials, while controlling for the time required to reject the distractor object (e.g. brush) which varies as a function of novelty (see Table 3).