

# 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

Many authors have argued that word-learning constraints help guide a word-learner's hypotheses as to the meaning 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 reject 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 shows that processing is similar for adults performing an *implicit* Disjunctive Syllogism (e.g. “the winner is the *dax*”) and an *explicit* Disjunctive Syllogism (e.g. “the winner is *not* the iron”). Experiment 3 reveals that similar processes govern preschoolers' mapping of novel labels. Taken together, these results suggest that word-learners use Disjunctive Syllogism to motivate the mapping of novel labels to novel objects.

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## 1. Introduction

During the past 20 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 infer that it refers to middle-sized drinking receptacles, 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; Smith, 1995, 1998), the non-linguistic directing of attention through pointing (Mervis, Golinkoff, & Bertrand, 1994) and the direction of a speakers' gaze (Baldwin et al., 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 (Booth & Waxman, 2002; Waxman & Booth, 2001; Waxman & Booth, 2000), 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 the cognitive hierarchy 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; Markman, Wasow, & Hansen, 2003). But, *how* does an infant or adult 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. 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 et al., 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 word-learning constraints. 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; Merriman & Bowman, 1989; Mervis & Bertrand, 1994; Mervis et al., 1994; Xu, Cote, & Baker, 2005) 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; Halberda, 2003; Merriman & Bowman, 1989; Mervis & Bertrand, 1994), (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; Litschwager & 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 each suggested some computational structure that underlies the use of constraints, these suggestions have remained untested as, to date, there has been no behavioral measure that might reveal them. In the present article I begin to develop these proposals into more specific computational accounts and attempt to bring behavioral evidence to bear on deciding among them.

### *1.1. Overview of the computations required by mutual exclusivity, contrast, a pragmatic account and novel-name nameless-category*

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 (Litschwager & 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’ cannot 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. In applying this constraint, a word-learner is reasoning in a manner consistent with pragmatic assumptions, e.g. that the requested object “dax” is physically present and is one of the two possibilities on the table (Clark and Marshall, 1981). 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, 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” were taken to refer to a part of the brush that lacked a known label, or by taking “dax” to label the brush under a different sense than basic-level-object kind (e.g. ‘Horse-hair brush’). Thus, in order to motivate the mapping of the novel label “dax” to the novel object, a child using Contrast may also make use of Markman’s Whole Object constraint (Clark, 1990, p. 423; Markman, 1989, 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 that could not be eliminated otherwise,” (Clark, 1990, 1993). These points could be captured by a number of different models at least one of which is consistent with Disjunctive Syllogism. 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 cannot refer to the brush (basic-level kind) because “brush” already refers to this category. Therefore, because I prefer to take “dax” as a label for a basic-level kind, “dax” must refer to the novel object.” In this case, the mapping of the novel label to the novel object would be motivated via the rejection of the known object (e.g. brush), a Disjunctive Syllogism.

A Pragmatic Account notes that, 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 at any level of cognition. Certainly these computations may be explicit and conscious, but they might just as easily be encapsulated and unconscious.

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-Novelty-to-Novelty.” In cases of referential ambiguity, N3C “predicts the selection of the unnamed object for the positive reason that children seek names for objects that are previously unnamed,” (Golinkoff et al., 1992). *A fortiori*, “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],” (Mervis & Bertrand, 1994). A word-learner utilizing N3C would not have to reject the known 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.

Three of the proposed principles suggest that the computation Disjunctive Syllogism may support the mapping of novel labels to novel objects: Mutual Exclusivity, Contrast, and a Pragmatic Account. The fourth suggests that information about the novel object is the most relevant and that rejection of distractor objects should play no causal role: N3C. What behaviors might help decide between these proposals?

## 1.2. Predicted behaviors indicative of disjunctive syllogism

In performing a Disjunctive Syllogism, 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”). The mapping of a novel label to a novel object must be motivated 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.” In order to execute a process-of-elimination, a word-learner would be required to bring the known object (e.g. brush) into the focus of attention to evaluate it and subsequently 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.

For N3C, no such rejection is required. This principle proposes that children are positively motivated to map novel labels to novel objects. For this reason the rate-determining information would involve the degree of novelty of the label “dax” and the visual or linguistic novelty of the novel object. A word-learner using N3C would not be required to attend and reject known objects during the mapping process. In the following experiments I lay out and test a number of specific predictions that follow from Disjunctive Syllogism’s requirement that word-learners reject known objects (e.g. brush) on their 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 during a trial and their reaction time

to point as a function of which object (target or distractor) is being fixated at the time of label onset. 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. Also, word-learners’ reaction time to map novel labels to novel objects should be a function of how quickly they can reject the known object distractor. The faster the known object (e.g. brush) can be rejected as a possible referent of the novel label (e.g. “dax”), the faster the resulting mapping of the novel label to the novel object will occur. Thus, throughout these experiments I will evaluate participants’ direction of gaze and reaction time to point on both Known (e.g. “point at the ball”) and Novel Label trials (e.g. “point at the dax”).

Eye-tracking has proved a valuable measure of on-line cognition and information-processing in problem solving (Grant & Spivey, 2003), pragmatic inference (Epley, Morewedge, & Keysar, 2004; Hanna & Tanenhaus, 2004; Hanna, Tanenhaus, & Trueswell, 2003; Keysar, Barr, Balin, & Brauner, 2000), and speech processing (Allopenna, Magnuson, & Tanenhaus, 1998; Dahan, Swingley, Tanenhaus, & Magnuson, 2000; Fernald, Pinto, Swigley, Weinberg, & McRoberts, 1998; Griffin & Bock, 2000; Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). For instance, during spoken word recognition (e.g. “point at the *beaker*”), eye movements to potential targets in the visual scene across time (e.g. beaker, speaker, beetle, carriage) have been fit to the predictions of continuous mapping models such as TRACE, a connectionist model of word recognition (Allopenna et al., 1998; McClelland & Elman, 1986). These results suggest that both children and adults evaluate possible referents (e.g. beaker, beetle) as constrained by the speech-stream as it unfolds in real-time. For pragmatic inference (Epley et al., 2004; Keysar et al., 2000), mental rotation (Just & Carpenter, 1985), geometrical reasoning (Epelboim & Suppes, 1997) and diagram-based reasoning (Grant & Spivey, 2003), eye movements to relevant areas of the scene correlate with the time-course of problem solving and with solution accuracy. In what follows, I will try to extend these results to the case of Disjunctive Syllogism and ask: will participants eye-movements indicate that they are explicitly considering and rejecting known object distractors (e.g. brush) prior to mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube)?

Before investigating the relevance of Disjunctive Syllogism for word-learning in both children and adults, it is reasonable to consider evidence that children will engage in reasoning via Disjunctive Syllogism and other deductive strategies more generally. When tests of explicit conscious reasoning are used, most studies find that children do not succeed at abstract logical tasks until 7 or 8 years of age (Chao & Cheng, 2000; Morris & Sloutsky, 2002; Sodian & Wimmer, 1987). Children will succeed at more naturalistic tasks that use verbal disjunction (i.e. “or”) at approximately 5 years of age (Hatano & Suga, 1977; Shine & Walsh, 1971; Suppes & Feldman, 1971). However, with tasks that allow children to make inferences implicitly, children as young as 2.5 years of age show some success on tasks that may require logical inference (Ackerman, 1978; Fabricius, Sophian, & Wellman, 1987; Macnamara, Baker, & Olson, 1976; Pea, 1982; Scholnick & Wing, 1995; Somerville & Capuani-Shumaker, 1984). For instance, when a toy is hidden in one of three possible locations and a child is told to find the toy, 3- to 4-year-olds increase their search rate as they systematically eliminate possible hiding places throughout their search (e.g. “the toy is either behind A or B or C, the toy is not behind A, the toy is not behind B, therefore...”) (Watson et al., 2001). This is consistent with the proposal that these children are performing a Disjunctive Syllogism (i.e. process-of-elimination). In this same task, domesticated



dogs decrease their search rate with each successive failure to find the toy, as if each failure serves as an extinction trial, consistent with an associatively-mediated search (Watson et al., 2001). For the present experiments, if adults and preschoolers appear to perform a Disjunctive Syllogism in the course of mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube), this computational structure may be part of a more general logical ability or it may be an unconscious mechanism specific to word-learning. If part of a general logical ability, the present work would converge with work on logical search behavior to suggest that Disjunctive Syllogism is domain-general for 3- to 4-year-old children. 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.

## 2. Experiment 1

Because the strategy of mapping novel labels to novel objects continues through adulthood (Golinkoff et al., 1992; Markman & Wachtel, 1988; Merriman & Bowman, 1989; Mervis et al., 1994), adults offer the opportunity to study the mental computations underlying the mature strategy. Experiment 1 is a simple test of the hypothesis that eye-movements will 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?

### 2.1. Method

#### 2.1.1. Participants

Participants were 20 college students (10 male) whose first language was English (mean age = 23 year, range = 18- to 31-year.). 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 or remaining fixated to a single screen throughout the study) and equipment failure (1).

#### 2.1.2. Stimuli

Visual stimuli consisted of 48 computer generated “3-D” objects from the TarrLab Object Data Bank (1996) and clip-art displayed on two computer monitors. Twelve of these were novel objects created by rearranging parts of nameless artifacts. Fig. 1 shows all of the objects and labels used throughout Experiments 1–3.

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 \_\_\_?”), which were used randomly throughout the study. Each object and each target label appeared only once during the study.

#### 2.1.3. Procedure

Adults participated in a version of the intermodal visual preference procedure (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987). Participants were tested in a sound-attenuated room. They sat facing two computer monitors that were approximately 50 cm away and



Fig. 1. The objects and labels used in Experiments 1–3. All objects appeared in color during the experiments.

72 cm apart at their centers (encompassing approximately 70° of visual angle). Objects appeared far enough into the periphery that an eye-movement was required to bring an object into the focus of attention. At the same time, objects were large and close enough together that while one object was being fixated the other was often visible in the periphery. Participants were told that they were playing a word-recognition game involving a wide range of possible objects. 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 simultaneously, one on each monitor. Objects were visible for 2 s prior to label onset (e.g. “\_brush”) during silence



and then during a carrier phrase (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, see Fig. 1). The known 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 a possible trial order from Experiment 1.

Trials were pseudo-randomized to ensure that a 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). Looking was coded without sound so that coders were not aware of which trial was being coded. Coders were blind as to the location of the target, the trial order, and the trial type. For each trial, coders assessed the single frame that marked the onset and offset of each look. Objects always appeared in the same location on the monitors. This allowed coders to assess looking to the two relevant locations without knowing which object was present. In general, participants were either fixating the left object, the right object, in transit during a switch, or fixating center. Coders recorded the frame on which a look to an object location began (i.e. the frame on which the participant's eyes first fell on the location), and the frame on which this look ended (i.e. the first frame on which the participant's eyes moved off of this location). Looks anywhere other than the two object locations were not recorded. Six randomly chosen participants were coded independently by two coders. Agreement on the occurrence and the location of looks was 100%. Coders agreed on the critical frames that marked the onset and the offset of each look with an average disagreement of  $\pm 1.55$  frames, which is equivalent to an error of  $\pm 52$  ms. This somewhat primitive method of eye-tracking allowed for an accurate assessment of fixations (i.e. 100% agreement on the occurrence and location of fixations) and a reasonably accurate estimation of temporal dynamics.

In addition to this looking-time measure, adults were administered a questionnaire after 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.

## 2.2. Results

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 the time spent looking at the target object

Table 1  
A possible trial order from Experiment 1

Trial	Participant's Left	Participant's Right
Practice 1	Brush	Watch
Practice 2	Paperclip	Screw
Practice 3	Keys	Motorcycle
Practice 4	Tack	Ball
Participant asked if she is ready to begin		
1	Pepper	Glasses
2	Bat	Axe
3	Door	Cup
4	Ratch	Trumpet
5	Lorp	Sissors
6	Pot	Bed
7	Iron	Pumpkin
8	Blick	Kite
9	Spoov	Wagon
10	Snail	Tife
11	Car	Spoon
12	Glark	Belt
13	Dax	Hat
14	Guitar	Pizer
15	Knife	Hat
16	Chair	Tanzer
17	Violin	Pipe
18	Flashlight	Chatten
19	Pencil	Fork
20	Umbrella	Basket
21	Ruler	Clock
22	Desk	Krat
23	Bell	Zav
24	Bike	Pen

Note. Labeled object is circled.

divided by the total time spent looking at either object multiplied by 100. Looks not directed to either object were not included. Thus, chance looking both before and after the label was 50%.

Percent looking to the target object both before and after label onset was computed for each participant 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  $\times$  2 Measurement Period (before and after label onset)  $\times$  2 Trial Order

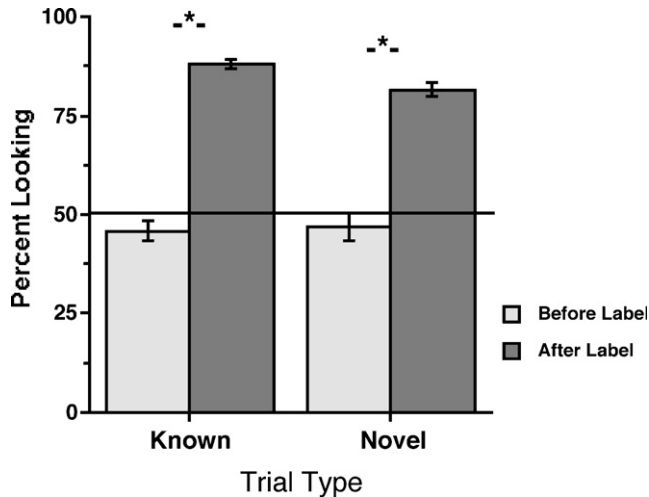


Fig. 2. Percent-looking ( $\pm SE$ ) to the target object before and after label onset in Experiment 1. Percent-looking is equal to the time spent looking at the target, divided by the time spent looking at either object times 100. Thus, chance looking is 50%. The significant increase in percent looking following label onset indicates that adults succeeded on both Known and Novel Label trials. \*Indicates  $p < .05$ .

repeated measures ANOVA. All statistical tests were performed at a significance level of  $p < .05$ , however, in keeping with current trends I have reported  $p$ -values up to  $p < .001$  whenever appropriate. 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 Fig. 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).<sup>1</sup>

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 known object (e.g. “dax does *not* refer to the brush”). On trials when 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 known object distractor (e.g. brush) in order to reject it as a possible referent of the novel label (e.g. “dax”). That is, participants should shift fixation from the target (e.g. phototube) to the known object (e.g. brush), reject it, and then shift fixation back to the target (e.g. phototube).

<sup>1</sup> I will refer to an example of a novel object, a phototube, throughout. Pilot testing suggested that adults did not know a name for any of the novel objects used (e.g. Fig. 1).

Shifts in fixation back to the known object distractor (e.g. brush) may not occur on every trial. Because participants have already had an opportunity to fixate both objects 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-Novelty-to-Novelty, or because they perform a Disjunctive Syllogism from information stored in memory (e.g. “dax” cannot refer to the other object; because I already know that object is a brush). Also, the absolute number of double-checks may be affected by factors orthogonal to Disjunctive Syllogism (e.g. double-checks might increase or decrease as a function of the distance between objects, the amount of time prior to label onset, the familiarity of the participant with the surroundings, etc). For these reasons, I am not interested in the *absolute* number of double-checks performed on target-fixated Novel Label trials (looking at phototube, hearing “dax”), though I hope they will be relatively frequent. Instead, I predict a *significant increase* in double-checks on target-fixated Novel Label trials (where rejecting the distractor is a necessary step in a Disjunctive Syllogism) *relative* to target-fixated Known Label trials (looking at ball, hearing “look at the ball”), where rejecting the distractor (e.g. cup) is not required. This comparison will control for participants’ baseline tendency to perform double-checks and will serve as a measure of the relative importance of information about the distractor object on Known (e.g. “ball”) and Novel (e.g. “dax”) Label trials.

On 90% of trials, participants happened to be fixating either the target or the distractor at the time of label onset. Percent-looking was combined within-participant for each of the relevant trial types (e.g. target-fixated Known Label trials). I took an average of the looking that occurred within each 250 ms time slice following label onset for each participant. These averages are plotted in Fig. 3 (e.g. time slice 0–250 ms plotted at its midpoint, 125 ms in Fig. 3a). Each participant contributed a single average to each time slice for each trial type. Thus, error bars in Fig. 3 indicate the standard error of participant means.

In frame-by-frame analyses, changes in fixation that occur within the first 150 ms following label onset are often discarded. Because it can take as much as 200 ms to execute an eye-movement once it has been planned, it is likely that eye movements initiated during the first 150 ms following label onset are movements that were planned prior to hearing the label. Because I am interested in ‘double-checks’ on target-fixated trials, and I have no prior data to suggest at what point after label onset such double-checks should occur, I did not filter out eye-movements occurring during the first 150 ms following label onset. Every change in fixation is included in Fig. 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 Fig. 3a. Participants maintained fixation on the target object (e.g. ball) following label onset (e.g. “ball”). I scored double-checks as the percent of trials on which a participant was fixating the target at the time of label onset, switched fixation to the distractor and returned gaze to the target before trial offset. Using this criterion, adults double-checked the known object distractor (e.g. cup) on 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 (relative 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 Figs. 3b and c. Adults double-checked the known object distractor before returning

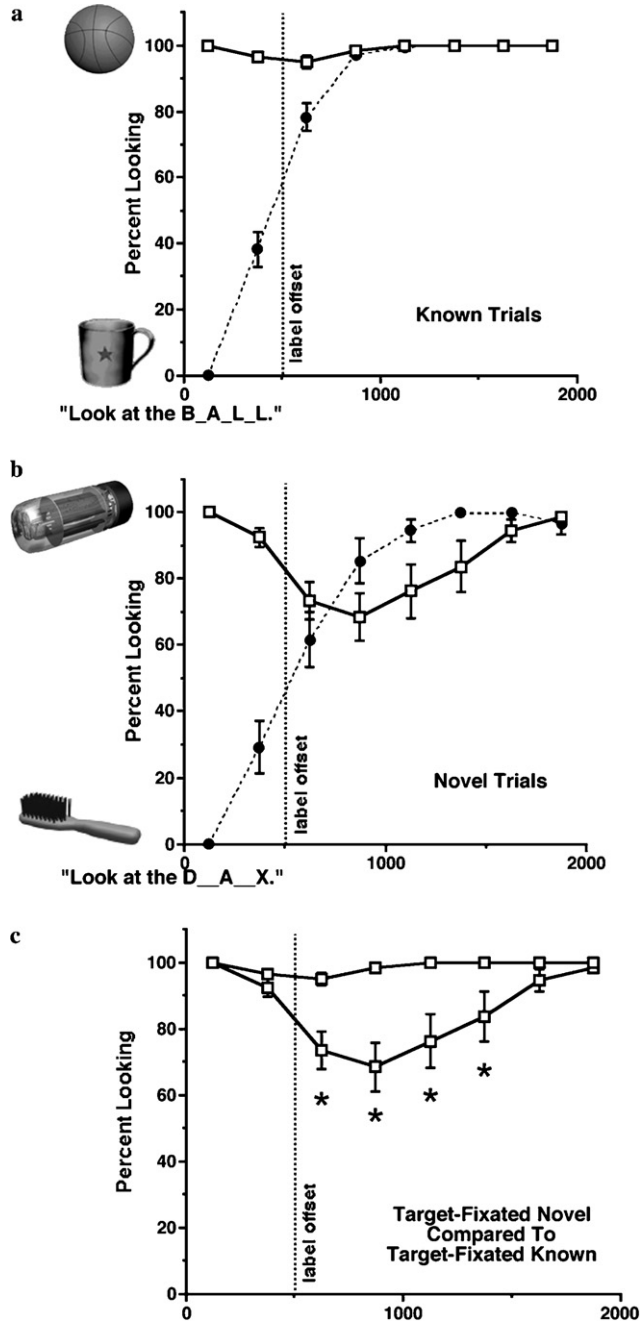


Fig. 3. Percent-lookup ( $\pm SE$ ) to the target object is displayed for trials on which participants happened to be fixating either the target (open boxes) or distractor (filled circles) at time of label onset in Experiment 1. Percent-lookup is displayed for Known (a), Novel (b), and Known and Novel combined (c) from the time of label onset (0 ms) to trial offset (2000 ms) for successive time-slices constructed from participant means. Participants significantly increased double-checking of the distractor object on Novel compared to Known Label trials (c). \*Indicates  $p < .05$ . Example trials and demos can be viewed at <http://www.psy.jhu.edu/~halberda/demos.html>.

gaze to the novel target on 76% of target-fixated Novel Label trials ( $SE = 7.28$ ). Comparing percent-looking in each 250 ms time slice for target-fixated Known Label trials to target-fixated Novel Label trials (Fig. 3c) reveals that percent looking on target-fixated Novel Label trials begins to diverge at approximately 400 ms following label onset and that it is significantly different by 625 ms: 3rd time slice,  $t(19) = 3.724$ ,  $p < .001$ . Overall, there was a significant increase in the percent of trials that included a double-check on target-fixated Novel Label trials (76%) compared to target-fixated Known Label trials (16%) as measured by a paired-samples  $t$ -test:  $t(19) = 6.79$ ,  $p < .001$ .

Considering that 76% of target-fixated Novel Label trials included a double-check, one might expect percent looking in Fig. 3b to drop as low as 24% by simply subtracting the percent of trials on which participants double-checked (76%) from all possible trials (100%). The reason why percent looking does not drop this low at any single point in Fig. 3b is that participants performed double-checks at varying times during the trial.

Were the double-checks performed on target-fixated Novel Label trials (looking at phototube, hearing “dax”) causally related to adults’ mapping of novel labels to novel objects? Disjunctive Syllogism predicts that information about the known object distractor (e.g. brush) should be the rate-determining information for mapping a novel label (“dax”) to a novel object (phototube). To test this prediction, I normalized looking on the target-fixated Novel Label trials on which participants performed a double-check to the moment at which participants returned fixation to the known object distractor (e.g. brush). If information about the known object distractor (e.g. brush) is the rate-determining information for mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube) then percent-looking on these normalized trials should show the same systematic rejection of the known object distractor (e.g. brush) that is observed on *distractor*-fixated Novel Label trials (looking at brush, hearing “dax”) from the moment of label onset. According to Disjunctive Syllogism, information about the known object distractor (e.g. brush) should control participants’ responses. In Fig. 4, we see that this is the case. Even though participants are double-checking the known object at different times during the trial, once participants returned their gaze to the known object, the subsequent pattern of looking resembles that seen on distractor-fixated Novel Label trials (looking at brush, hearing “dax”) suggesting that it is information about the known object distractor (e.g. brush) and *not* information about the novel object (e.g. phototube) that is controlling participants’ responses.<sup>2</sup>

Participants had fixated both the target and the distractor object prior to label onset on 73% of trials. Fig. 5 presents an analysis of percent looking limited to only these trials (on which double-checking the distractor object is unnecessary as both objects have been fixated prior to label onset). The results were the same. Participants showed a significant increase in double-checks of the distractor object on target-fixated Novel Label trials (49%) (looking at phototube, hearing “dax”) compared to target-fixated Known Label trials (7%) (looking at ball, hearing “ball”):  $t(14) = 3.838$ ,  $p < .002$ .<sup>3</sup>

<sup>2</sup> It is 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 Fig. 3b), by which time participants would have processed the entirety of the novel label.

<sup>3</sup> Five of the 20 participants could not be included in this within-subject  $t$ -test because of missing data in one or more conditions due to the more limited number of trials included.



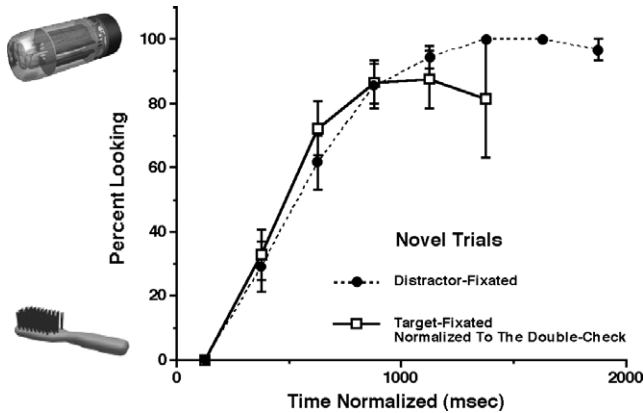


Fig. 4. Percent looking ( $\pm SE$ ) is displayed for distractor- and target-fixated Novel Label trials in Experiment 1. For target-fixated trials, looking time has been normalized to the moment at which participants had shifted fixation back to the known object distractor (e.g. brush) during a double-check. 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).

Adults were given a short questionnaire following their participation in the study to assess their 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 appeared convinced that the novel objects were uncommon real objects and 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 looked through the camera and observed 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. known object).”). 100% of participants gave answers consistent with Disjunctive Syllogism.

### 2.3. Discussion

An analysis of looking time suggests that adults systematically reject known object distractors (e.g. brush) before mapping novel labels (e.g. “dax”) to novel objects (e.g. phototube). Both the pattern of double-checks observed on target-fixated Novel Label trials, and participants’ own verbal report are consistent with the proposal that Disjunctive Syllogism underlies the mapping of novel labels to novel objects.

## 3. Experiment 2

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 (e.g. “the winner is *not* the iron”).

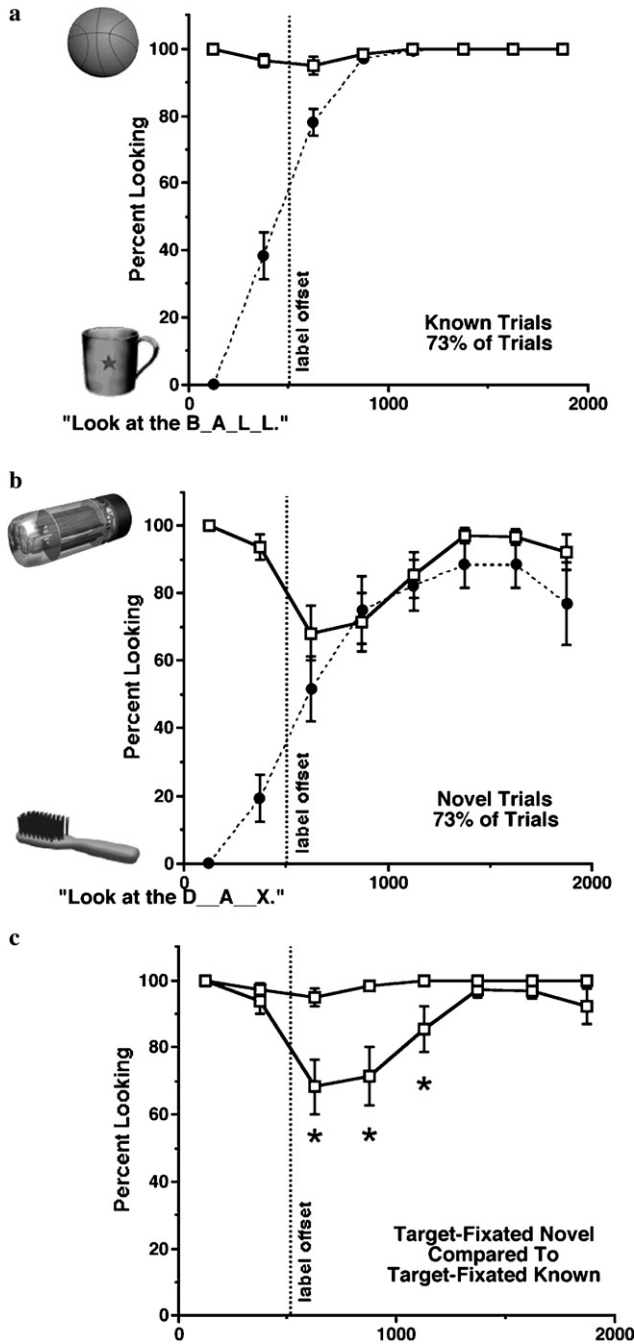


Fig. 5. Percent-looking ( $\pm SE$ ) is displayed for only those trials on which participants had fixated both the target and distractor object prior to label onset (73% of all trials) in Experiment 1. At the time of label onset (0 ms) participants happened to be fixating either the target (open boxes) or the distractor (filled circles). Percent-looking is displayed for Known (a), Novel (b), and Known and Novel combined (c). Participants significantly increased double-checking of the distractor object on Novel compared to Known Label trials (c). \*Indicates  $p < .05$ .

Imagine that a participant is presented with two objects (e.g. iron and pumpkin) and asked to “find the winner” between these two. If the 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 participants 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 participants are told “the winner is the *dax*” should match parametrically those observed when participants are told “the winner is *not* the iron.”

### 3.1. Method

#### 3.1.1. Participants

Participants were 10 new adults (5 male) whose first language was English (mean age = 23 year, range = 18- to 31-year). 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 point (1) and equipment failure (1).

#### 3.1.2. Stimuli

Visual stimuli were the same as those used in Experiment 1 along with 8 additional objects as Experiment 2 included 28 test trials instead of the 24 used in Experiment 1 (these 8 objects are also included in Fig. 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.

#### 3.1.3. 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.

Experiment 1 demonstrated that participants tend to double-check the known object distractor (e.g. brush) on target-fixated Novel Label trials (looking at phototube, hearing “dax”) even when they have already fixated it prior to novel label onset (e.g. “dax”). But, consider the trials on which participants have *not* fixated the known object distractor prior to novel label onset. On these trials, participants should “double-check” the known object distractor on nearly 100% of target-fixated Novel Label trials (looking at phototube, hearing “dax”), if rejection of the known object distractor (e.g. brush) is a *necessary* step for mapping novel labels (e.g. “dax”) to novel objects (e.g. phototube). To evaluate this prediction, participants in Experiment 2 were given time to fixate only one object (target or distractor) prior to label onset. During each trial the carrier phrase began before the pictures were presented (e.g. “The winner is the ball.”). Approximately 250 ms before the onset of the label (“ball”), two objects appeared, one on each monitor, simultaneously. Participants typically fixated only one of these objects before the label was spoken (89%

of all trials). Following label onset, comprehension looking was measured for 3.5 s (i.e. 1.5 s longer than in Experiment 1 because participants were expected to need extra time to process explicit negation). After this 3.5 s 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.

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. Fig. 1). On 4 of these trials, participants were told, “The winner is the [known object],” on 4 others they were told, “The winner is *not* the [known object],” and on 4 trials participants were told, “The winner is the [novel object],” on 4 others 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 were asked to both look and point to the winning object on all trials. Reaction time to point was coded along with looking. The measure of pointing was used because it allowed participants to maintain fixation on the objects while pointing (as opposed to key presses that might lead participants to break fixation), and because this method also works well for young children. Participants were asked to hold their left and right hands in the form of fists on their chins beside their cheeks and to use their index fingers to point to the winner on each trial; left index finger extended to point to the left screen and right index finger extended to point to the right screen. Participants returned both hands to a fist position before the beginning of each trial. Pointing was coded as the moment of maximal extension of the finger towards the screen. The initiation of the point was not coded. Looking was coded as in Experiment 1. Two randomly chosen participants were coded independently by two coders. Agreement on the occurrence and the location of looks and points was 100%. Coders agreed on the critical frames that marked the onset and the offset of each look with an average disagreement of  $\pm 2.21$  frames, which is equivalent to an error of  $\pm 73$  ms. Coders agreed on the critical frames that marked the moment of maximal extension of the finger during a point with an average disagreement of  $\pm 2.54$  frames, which is equivalent to an error of  $\pm 85$  ms. This is acceptably accurate estimation of temporal dynamics for my purposes.

After completing the study, adults were presented with four post-test trials designed to test 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. Participants were asked to point to one of them (e.g. “could you point at the [dax]”) to test 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 as the target on a Novel Label trial (i.e. “the winner is the [dax]”). On the other two trials both objects had been presented as the distractor on a Not-Novel trial (i.e. “the winner is *not* the [tever]”). If participants 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 awareness of the strategy they had employed.

### 3.2. Results

Percent-looking following label onset served as a measure of success. Participants looked to the target object at above chance levels (50%) on all four trial types (Fig. 6) as measured by planned *t*-tests: Known trials, 78.9%,  $t(9) = 16.61$ ,  $p < .001$ ; Not-Known trials, 80.2%,  $t(9) = 13.98$ ,  $p < .001$ ; Novel trials, 74.7%,  $t(9) = 9.69$ ,  $p < .001$ ; Not-Novel trials, 64.0%,  $t(9) = 2.70$ ,  $p < .05$ .

Fig. 7 displays the frame-by-frame coding of participants' looking throughout Known (a), Novel (b), Not-Known (d), and Not-Novel (e) trials for trials on which participants happened to be fixating either the target or the distractor object at time of label onset. This accounted for 95% of trials.

I will first consider performance on Known and Novel trials. On the left side of Fig. 7, the results of Experiment 1 are replicated. Critically, on target-fixated Known trials (looking at ball, hearing “ball”), participants double-checked the distractor (e.g. cup) on 36.3% of trials ( $SE = 12.78$ ). In contrast, on target-fixated Novel trials (looking at phototube, hearing “dax”) participants double-checked the distractor object on 96.8% of trials ( $SE = 3.13$ ). This difference was significant as measured by a planned within-subject *t*-test:  $t(7) = 4.56$ ,  $p < .005$ . As seen in Fig. 7c, this difference in looking became significant by 875 ms after label onset as measured by within-subject *t*-tests on each time slice. This difference compared to Experiment 1 (Fig. 3c, 625 ms) is likely due to participants' greater tendency to double-check objects in Experiment 2 (Fig. 7) compared to Experiment 1 (Fig. 3). Sources of this difference include the briefer exposure participants had to the objects in Experiment 2 before label onset and the inclusion of explicit negation on some trial types. In Fig. 8 percent-looking on target-fixated Novel trials (looking at phototube,

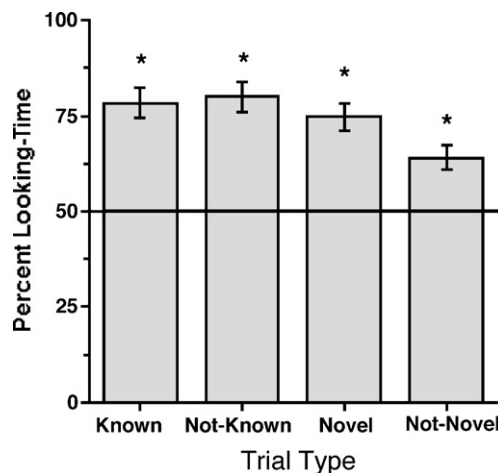


Fig. 6. Percent-looking ( $\pm SE$ ) to the target object after label onset is displayed for each Trial Type in Experiment 2 (chance = 50%). Adults succeeded on all trial types. \*Indicates  $p < .05$ .

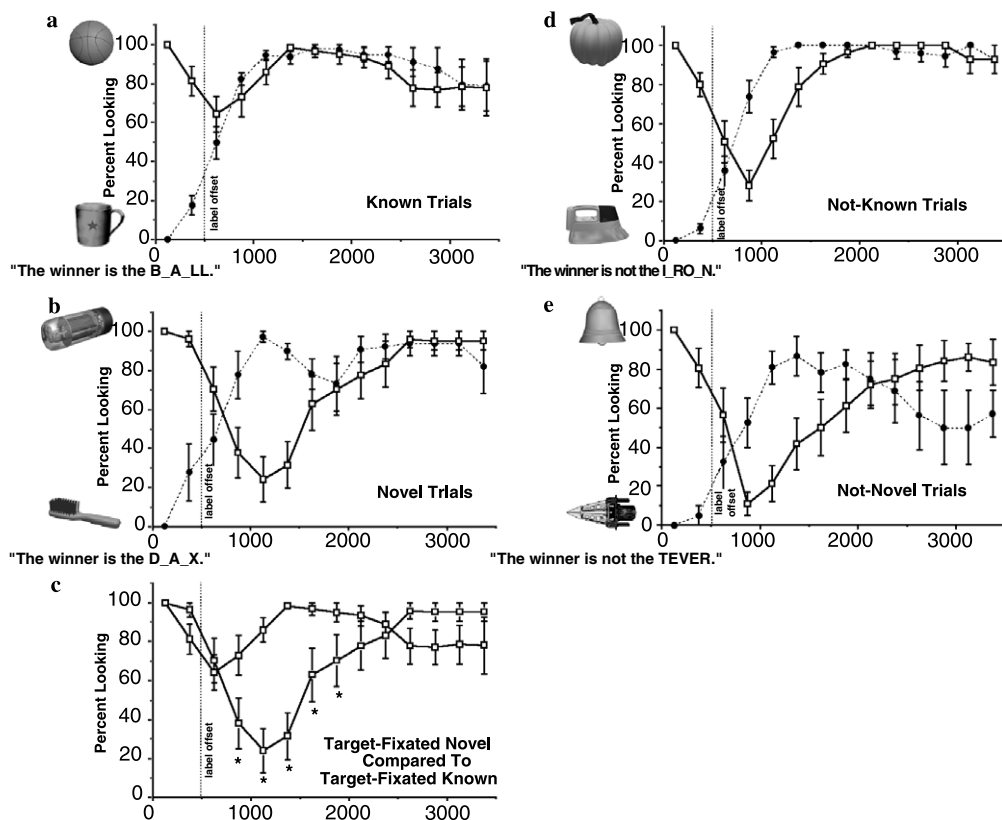


Fig. 7. Percent-looking ( $\pm SE$ ) to the target object is displayed for trials on which participants happened to be fixating either the target (open-boxes) or distractor (filled-circles) at time of label onset in Experiment 2. Percent-looking is displayed for Known (a), Novel (b), Known and Novel combined (c), Not-Known (d), and Not-Not-Known trials (e) from the time of label onset (0 ms) to trial offset (3500 ms). The pattern of eye-movements observed on Novel trials (e.g. “the winner is the dax”) is parametrically matched to the pattern observed on Not-Known trials (e.g. “the winner is not the iron”), as predicted by Disjunctive Syllogism. \*Indicates  $p < .05$ . Example trials and demos can be viewed at <http://www.psy.jhu.edu/~halberda/demos.html>.

hearing “dax”) that included a double-check has been normalized to the moment at which participants returned their gaze to the known object distractor (e.g. brush). As predicted by Disjunctive Syllogism, the resulting pattern of looking resembles that seen on *distractor*-fixated Novel trials (looking at bush, hearing “dax”). There is a non-significant drop in looking on distractor-fixated Novel trials (Fig. 8) that is likely due to the subset of trials on which participants planned to execute a switch before having heard the novel label. Because a switch in gaze on these trials was not motivated by hearing the novel label (e.g. “dax”) and because of the limited exposure time to the objects prior to label onset (i.e. 250 ms), these trials may in essence be target-fixated trials and may require a double-check. The overall agreement between looking on distractor-fixated Novel trials (looking at brush, hearing “dax”) and normalized looking on target-fixated Novel trials (looking at phototube, hearing “dax”) suggests that information about the known object distractor (e.g. brush) is the rate-determining information for mapping a novel label to a



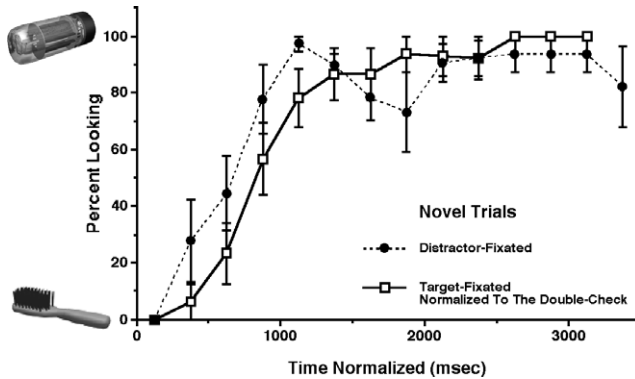


Fig. 8. Percent looking ( $\pm SE$ ) is displayed for distractor- and target-fixated Novel Label trials in Experiment 2. For target-fixated trials, looking time has been normalized to the moment at which participants had shifted fixation back to the known object distractor (e.g. brush) during a double-check. 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).

novel object. And, that participants double-checked the known object distractor on 96.8% of target-fixated Novel trials (looking at phototube, hearing “dax”) suggests that rejection of this object is a necessary step for mapping novel labels to novel objects. In a post-test questionnaire, participants were asked why they had chosen to point to a novel object when presented with a novel label. Ten out of ten participants gave responses that were consistent with Disjunctive Syllogism. Three participants went so far as to say, “I used process-of-elimination.”

Experiment 2 allowed for a more detailed analysis of the predictions of Disjunctive Syllogism on multiple trial types. Displayed in Fig. 7d, participants *also* increased their double-checks on target-fixated Not-Known trials (looking at pumpkin, hearing “not iron”) (93.8%,  $SE = 6.25$ ) compared to target-fixated Known trials (looking at ball, hearing “ball”) (36.3%,  $SE = 12.78$ ) as measured by a planned within-subject  $t$ -test:  $t(9) = 4.76$ ,  $p < .001$ . As predicted by Disjunctive Syllogism, double-checks on target-fixated Novel and Not-Known trials did not differ from each other (96.8 vs. 93.8%). If word-learners motivate the mapping of a novel label (e.g. “dax”) to a novel object (e.g. phototube) via rejection of the known object distractor (e.g. brush), then both Novel and Not-Known trials involve a Disjunctive Syllogism. Disjunctive Syllogism predicts the significant increase in double-checks observed on Novel and Not-Known trials and the overall similarity of the looking patterns on these trials (Figs. 7b and d). One difference between these trials is that participants’ switches in gaze were faster and showed less temporal variability on Not-Known trials compared to Novel trials (Figs. 7b and d). A reason for this difference is that, on Not-Known trials, the rejection of the disjunct (e.g. iron) requires participants to detect a *match* between the distractor (e.g. iron) and the label (e.g. “not the *iron*”) while on Novel trials rejection of the disjunct (e.g. brush) requires participants to detect a *mismatch* between the distractor (e.g. brush) and the label (e.g. “dax”). Thus, while the reasoning in both cases may well be a Disjunctive Syllogism (e.g. Not-Known, “The winner is either the pumpkin or the iron, the winner is not the iron, therefore the winner is the pumpkin”; Novel, “The winner is either the brush or the novel object, the winner is not the brush, therefore the winner is the novel object”), differences internal to the rejection

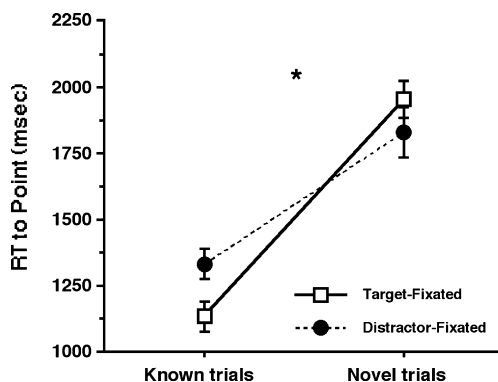


Fig. 9. Mean reaction time to point at the target object ( $\pm SE$ ) is displayed for Known (e.g. “ball”) and Novel (e.g. “dax”) trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, the interaction is significant,  $*p < .01$ .

required on these trials may account for differences in the details of what are globally similar patterns of looking.

There is another important parallel between Not-Known and Novel trials. According to Disjunctive Syllogism, information about the *distractor* object should be the rate-determining information for each of these trial types (e.g. rejecting the iron or rejecting the brush). For this reason, I predict that point times will be faster on *distractor*-fixated trials compared to *target*-fixated trials for both Novel and Not-Known trials. In contrast, information about the *target* object should be the rate-determining information on *Known* trials (e.g. “ball”). If told, “the winner is the ball,” the rate-determining information for deciding to point to the ball resides in the ball itself; no information about the distractor (e.g. cup) is required. Therefore, I predict that point times on *target*-fixated Known trials (looking at ball, hearing “ball”) will be faster than point times on *distractor*-fixated Known trials (looking at cup, hearing “ball”), leading to a predicted Trial Type (e.g. Known, Not-Known) by Object Fixated at time of label onset (target, distractor) interaction for both Not-Known and Novel trials compared to Known trials.

These predictions were confirmed. The predicted Trial Type (Known, Novel) by Object Fixated at time of label onset (target, distractor) interaction proved significant for Novel trials in a repeated measures ANOVA on point times and can be seen in Fig. 9:  $F(1, 7) = 13.48$ ,  $p < .01$ . Comparing Known and Not-Known trials, the predicted Trial Type (Known, Novel) by Object Fixated at time of label onset (target, distractor) interaction also proved significant in a repeated measures ANOVA on point times and can be seen in Fig. 10:  $F(1, 9) = 13.92$ ,  $p < .005$ .<sup>4</sup> These interactions suggest that for Novel (e.g. “the winner is the dax”) and Not-Known trials (e.g. “the winner is not the iron”), information about the distractor object (e.g. iron or brush) is the rate-determining information for reaching a decision to point. Because Not-Known trials involve explicit negation (e.g. “the winner is not the iron”), and therefore unambiguously require participants to perform a Disjunctive Syllogism (e.g. the winner is either the iron or the pumpkin, the winner

<sup>4</sup> Point times on Not-Known trials were faster than point times on Novel trials. This difference is consistent with the related differences already discussed for reaction time to switch fixation (Figs. 7b and d).

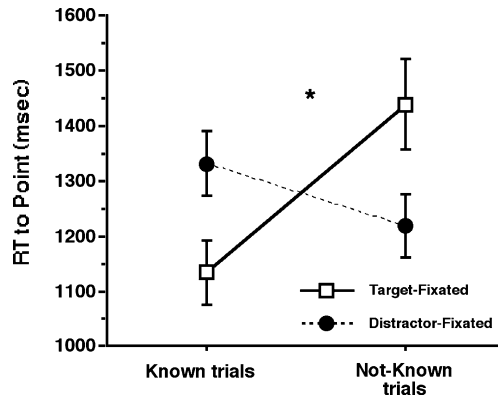


Fig. 10. Mean reaction time to point to the target object ( $\pm SE$ ) is displayed for Known (e.g. “ball”) and Not-Known (e.g. “not the iron”) trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, the interaction is significant,  $*p < .005$ .

is not the iron, therefore the winner is the pumpkin), the agreement between Novel and Not-Known trials further supports the hypothesis that Disjunctive Syllogism supports the mapping of novel labels (e.g. “dax”) to novel objects (e.g. phototube).

The fourth trial type, Not-Novel trials (e.g. “the winner is not the tever”), require participants to first decide what a “tever” *is* before they can decide what a “tever” *is not*. Not-Novel trials (e.g. “not the tever”) may be understood as a serial combination of two Disjunctive Syllogisms: a Novel trial (e.g. “tever”) followed by a Not-Known trial (e.g. “not the tever [newly learned]”).

On target-fixated Not-Novel trials (looking at bell, hearing “not the tever”), a serial Disjunctive Syllogism model predicts that participants will reject the known object (e.g. bell) as a possible referent of the novel label (e.g. “tever”) leading them to switch gaze to the distractor object (e.g. tever). Participants should then be motivated to map the novel label (e.g. “tever”) to the novel object (e.g. tever), having completed a Disjunctive Syllogism. Participants would then reject the newly learned novel object (e.g. tever) using explicit negation (e.g. “the winner is not the tever”) motivating participants to return gaze and point to the target (e.g. bell). Thus, the serial Disjunctive Syllogism model predicts a pattern of double-checks on target-fixated Not-Novel trials (looking at bell, hearing “not the tever”). This pattern was confirmed (Fig. 7e), participants performed a double-check before pointing to the target on 98.6% of target-fixated Not-Novel trials.

On distractor-fixated Not-Novel trials (looking at tever, hearing “not the tever”), the serial Disjunctive Syllogism model predicts a pattern of triple-checks. On these trials, participants should fail to find a match between the object fixated (e.g. tever) and the novel label (e.g. “tever”). This null result 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 (Mutual Exclusivity, Contrast, a Pragmatic Account). This would motivate 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). 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 reason using the explicit negation (i.e. “The winner is *not* the tever”). Participants should reject the novel object (e.g. tever) and point to the target (e.g. bell). Participants performed the predicted triple-check on 33.3% of distractor-fixated Not-Nov-el trials. This pattern can be seen in Fig. 7e (2250–3500 ms).

Further evidence that participants mapped the novel label (e.g. “tever”) to the novel object (e.g. tever) using Disjunctive Syllogism before rejecting it via explicit negation (e.g. “not the tever”) comes from the relative ordering of point times on these trials. Because a serial Disjunctive Syllogism model predicts fewer computations on target-fixated Not-Nov-el trials (i.e. a double-check) than on distractor-fixated Not-Nov-el trials (i.e. a triple-check), this model predicts that point-times on target-fixated trials should be faster than those on distractor-fixated trials. This is the *same* relative ordering that was predicted for Known trials. This prediction was confirmed in a 2 Trial Type (Known, Not-Nov-el)  $\times$  2 Object Fixated at time of label onset (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 Fig. 11, the relative ordering of point times on Not-Nov-el trials (e.g. “not the tever”) and Known trials (e.g. “ball”) were the same. This suggests that, while participants did not always perform a triple-check on distractor-fixated Not-Nov-el trials (looking at tever, hearing “not the tever”), they nonetheless took the time to map the novel label (e.g. “tever”) to the novel object (e.g. tever) before rejecting this object and pointing to the target (e.g. bell).

Did participants in fact *learn* the novel labels on both Novel (e.g. “dax”) and Not-Nov-el (e.g. “not the tever”) trials? Following the experiment, on four post-test trials, participants were asked to point to one of two novel objects. Pointing was compared to the chance level of 50%. As seen in Fig. 12, participants performed at above chance levels for words learned on both Novel and Not-Nov-el trials: Novel (85%),  $t(9) = 4.58$ ,  $p < .001$ , Not-Nov-el (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”) as measured by a planned

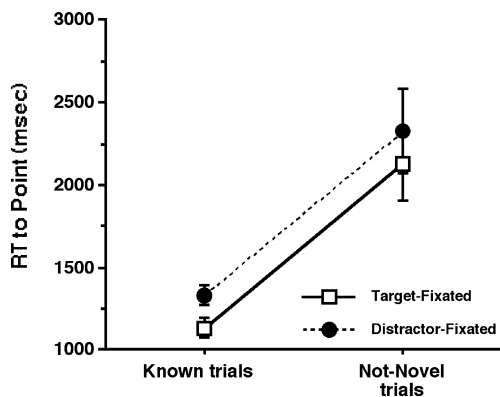


Fig. 11. Mean reaction time to point at the target object ( $\pm SE$ ) is displayed for Known (e.g. “ball”) and Not-Nov-el (e.g. “not the tever”) trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 2. As predicted by Disjunctive Syllogism, there is no significant interaction.

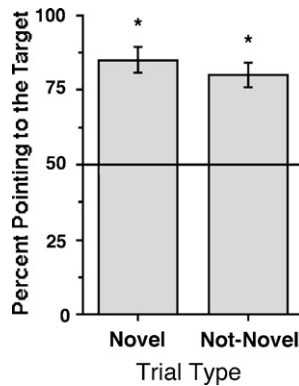


Fig. 12. The percentage of trials on which participants correctly identified the target object on post-test trials of fast-mapping in Experiment 2 ( $\pm SE$ ). Participants successfully learned the novel labels (e.g. “dax,” “tever,” etc.) on both Novel (e.g. “the winner is the dax”) and Not-Novel trials (e.g. “the winner is not the tever”). This supports a serial Disjunctive Syllogism model by which participants first learned the novel label (e.g. “tever”) before reasoning over explicit negation (e.g. “not the tever”). \*Indicates  $p < .05$ .

within-subject  $t$ -test:  $t(9) = 0.43$ ,  $p = .678$ . This supports the hypothesis that participants first decided which object was the “tever,” before reasoning over explicit negation, “the winner is not the tever.”

### 3.3. Discussion

The results of Experiment 2 are consistent with the proposal that both Novel (e.g. “dax”) and Not-Known (e.g. “not the iron”) trials require a Disjunctive Syllogism and that Not-Novel trials (e.g. “not the tever”) require a serial combination of the reasoning required by a Novel trial (e.g. “tever”) and a Not-Known trial (e.g. “not the tever [newly learned]”).

## 4. Experiment 3

The results of Experiments 1 and 2 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 to use explicit deductive strategies. 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. Children may not have access to an explicit top-down strategy. Experiment 3 asks: will preschool children also motivate the mapping of novel labels to novel objects via the systematic rejection of known object distractors?

### 4.1. Method

The method was identical to that in Experiment 1 except that preschoolers were asked to point to and look at the correct object, and were given an extra 1000 ms to do so.

#### 4.1.1. Participants

Participants were 10 preschool children (5 male) from predominantly English-speaking, middle-class families in the area surrounding the Johns Hopkins University campus, Baltimore, Maryland (mean age = 3 year, 8 months, range = 3 year, 1 month to 4 year, 4 months). Prior to participation, parents were administered a short inventory of their child's word knowledge composed of the common names of the 44 known objects used in the study (e.g. Fig. 1). This information was used to check that the known object choices were in fact known. Parents reported that their children both understood and said the names of on average 80% of the "known" objects used in Experiment 3. This was deemed an acceptable level of word knowledge. While parents sometimes reported that their child did not know the names of some of the "known" objects, no trials were changed and no children were removed from the study due to a lack of word knowledge. Four additional preschoolers were tested but not included in the final sample due to bilingualism (1), fussiness (2), and equipment failure (1).

#### 4.1.2. Stimuli

The stimuli were identical to those in Experiment 1.

#### 4.1.3. Procedure

The procedure was identical to that in Experiment 1, except that preschoolers were given 3000 ms both before and after label onset (e.g. "ball") to look at the objects. Caregivers, if present, sat approximately 4 ft. directly behind the child and were instructed not to speak. This eliminated any potential confound of the caregiver cueing the child's looking. Looking was recorded and coded as in Experiment 1. Two randomly chosen participants were coded independently by two coders. Agreement on the occurrence and the location of looks was 100%. Coders agreed on the critical frames that marked the onset and the offset of each look with an average disagreement of  $\pm 62$  frames, which is equivalent to an error of  $\pm 21$  ms. This is acceptably accurate estimation of temporal dynamics for my purposes. For pointing, children were not asked to hold their hands beside their face as was done for adults in Experiment 2 and were free to use either hand to point. Point times were coded as the moment of maximal extension of the arm and index finger. Only the first point after label onset was coded on each trial. Agreement on the occurrence and the location of points was 100%. Coders disagreed on the critical frames that marked the moment of maximal extension of points with an average disagreement of  $\pm 1.68$  frames or  $\pm 56$  ms.

#### 4.2. Results

Preliminary analyses revealed that children succeeded on both Known trials with a known distractor and Known trials with a novel distractor. These were therefore combined as "Known Label trials" for all further analyses. 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 as seen in Fig. 13: Known Labels, +27.3%,  $t(9) = 8.11$ ,  $p < .001$ ; Novel Labels, +24.3%,  $t(9) = 4.62$ ,  $p < .001$ .

Did preschoolers use Disjunctive Syllogism to map novel labels (e.g. "dax") to novel objects (e.g. phototube)? Do preschoolers, like adults, show a tendency to double-check the known 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)?



Fig. 14 shows the frame-by-frame coding of looking-time for Known and Novel Label trials (computed from participant 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.

The pattern of looking for preschoolers replicates that of adults observed in Experiment 1 (e.g. Fig. 3). Crucially, as can be seen in Fig. 14c, preschoolers showed a significant increase in double-checks of the distractor object on target-fixated Novel trials (63.33%,  $SE = 11.78$ ) compared to target-fixated Known trials (20.80%,  $SE = 3.78$ ) as measured by a planned within-subjects  $t$ -test:  $t(9) = 3.41$ ,  $p < .01$ . This suggests that preschoolers are rejecting the known object (e.g. brush) prior to mapping the novel label (e.g. “dax”) to the novel object (e.g. phototube). As can be seen in Fig. 14c, this difference between target-fixated Known trials and target-fixated Novel trials became significant by 1125 ms after label onset (i.e. 5th time-slice).

Disjunctive Syllogism predicts that information about the known object distractor (e.g. brush) should be the rate-determining information for mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube). Therefore, if looking on target-fixated Novel trials with a double-check (looking at phototube, hearing “dax”) is normalized to the moment at which participants had returned fixation to the known object distractor (e.g. brush), the subsequent looking should resemble that seen on *distractor*-fixated Novel trials (looking at brush, hearing “dax”). In Fig. 15 we see that this is the case.

Figs. 14 and 15 include all trials on which participants happened to be fixating either the target or distractor at time of label onset (90% of trials). As in Experiment 1, preschoolers had in general fixated both objects before label onset (71% of trials). Double-checking is unnecessary on these trials. When the analysis is restricted to this 71% of trials, consistent with the analysis of all trials, preschoolers show a significant increase in double-checks of the distractor object on target-fixated Novel trials (looking at phototube, hearing “dax”) (58.3%,  $SE = .14$ ) compared to target-fixated Known trials (looking at ball, hearing

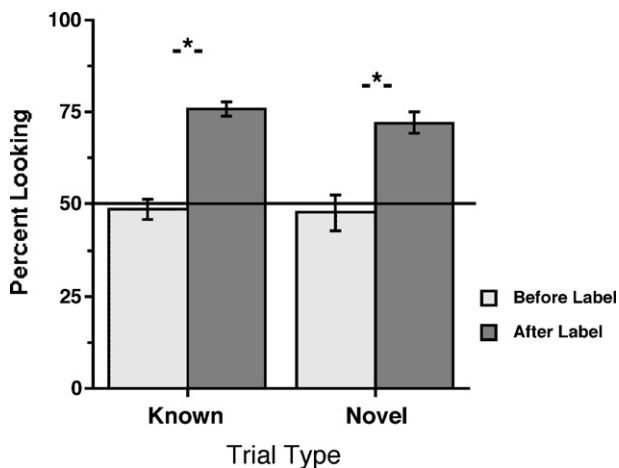


Fig. 13. Percent-looking ( $\pm SE$ ) to the target object both before and after label onset in Experiment 3 constructed from participant means. The significant increase in percent looking after label onset indicates that preschoolers succeeded on both Known (“ball”) and Novel Label trials (“dax”). \*Indicates  $p < .05$ .

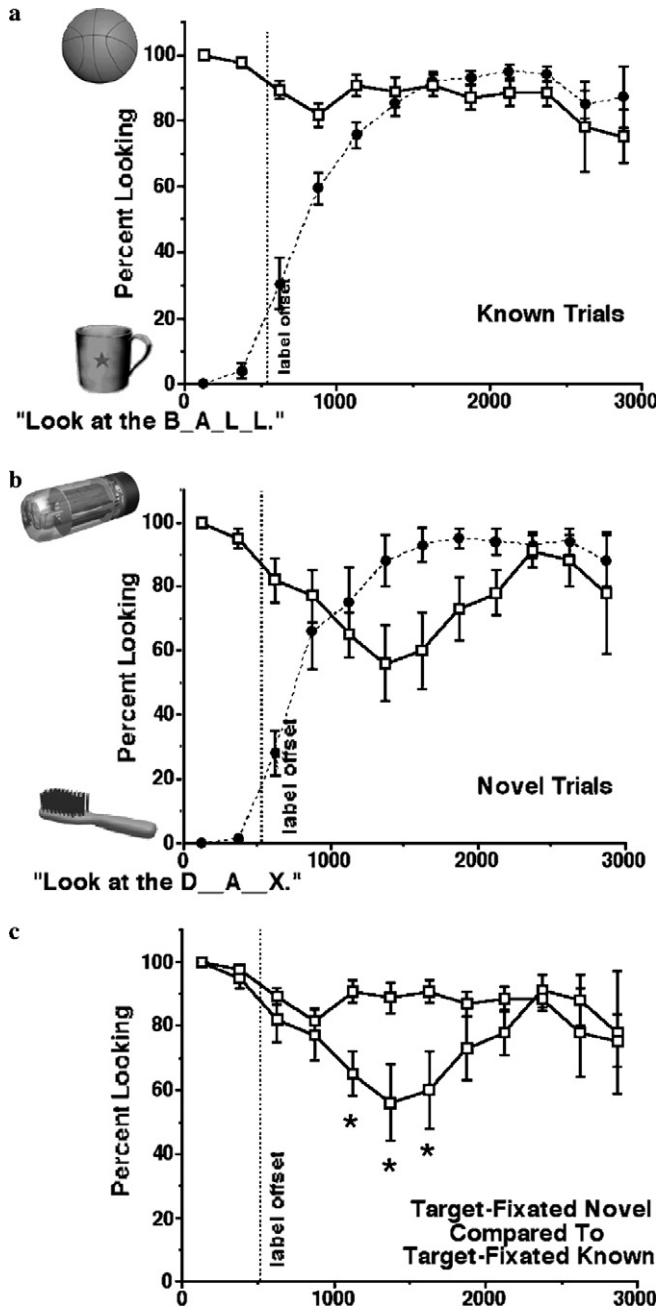


Fig. 14. Percent-lookup ( $\pm SE$ ) to the target object is displayed for trials on which participants happened to be fixating either the target (open-boxes) or distractor (filled-circles) at the time of label onset in Experiment 3. Percent-lookup is displayed for Known (a), Novel (b), and Known and Novel combined (c) from the time of label onset (0 ms) to trial offset (3000 ms) for successive time-slices constructed from participant means. Preschoolers showed a significant increase in double-checks of the distractor object (e.g. brush) on Novel Label (e.g. "dax") compared to Known Label trials (e.g. "ball") (c), as predicted by Disjunctive Syllogism. \*Indicates  $p < .05$ . Example trials and demos can be viewed at <http://www.psy.jhu.edu/~halberda/demos.html>.

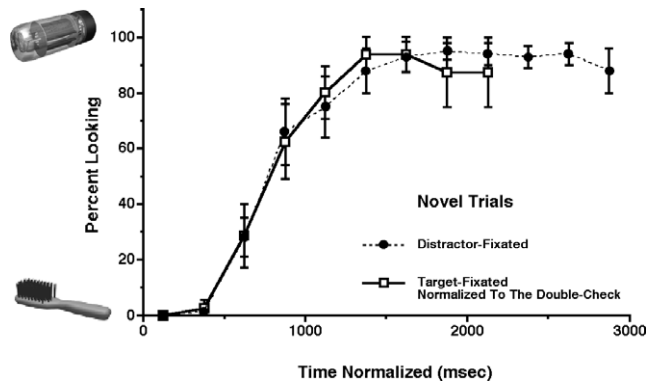


Fig. 15. Percent looking ( $\pm SE$ ) is displayed for distractor- and target-fixated Novel Label trials in Experiment 3. For target-fixated trials, looking time has been normalized to the moment at which participants had shifted gaze back to the known object (e.g. brush) during a double-check. The similarity 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).

“ball”) (19.4%,  $SE = .05$ ) as measured by a within-subject  $t$ -test (Figs. 16a–c),  $t(7) = 2.543$ ,  $p < .05$ .<sup>5</sup>

As in Experiment 2, children were asked to point as well as look at the correct object. If preschoolers use Disjunctive Syllogism to map novel labels to novel objects, point times on target-fixated Novel trials (looking at phototube, hearing “dax”) should be *longer* than point times on distractor-fixated Novel trials (looking at brush, hearing “dax”) resulting in a significant Trial Type (Known, Novel) by Object Fixated at the time of label onset (target, distractor) interaction. As seen in Fig. 17, this predicted interaction was significant as measured by a 2 Trial Type  $\times$  2 Object Fixated Repeated Measures ANOVA:  $F(1, 9) = 13.75$ ,  $p < .005$ .

#### 4.3. Discussion

Patterns of fixations and reaction times to point support the hypothesis that, as with adults, preschoolers rely on Disjunctive Syllogism to motivate the mapping of novel labels (e.g. “dax”) to novel objects (e.g. phototube).

### 5. 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 have been few continuous measures suitable to the limited behavioral repertoire of young children. As has been the case with recent gains in studying the development of both spoken-word recognition (Fernald et al., 1998) and pragmatic inference (Epley et al., 2004), the method of eye-tracking may help to fill this void. In the present article, I have used eye-tracking and reaction times in an attempt to uncover the mental

<sup>5</sup> Two of the 10 participants could not be included in this analysis because of empty cells.

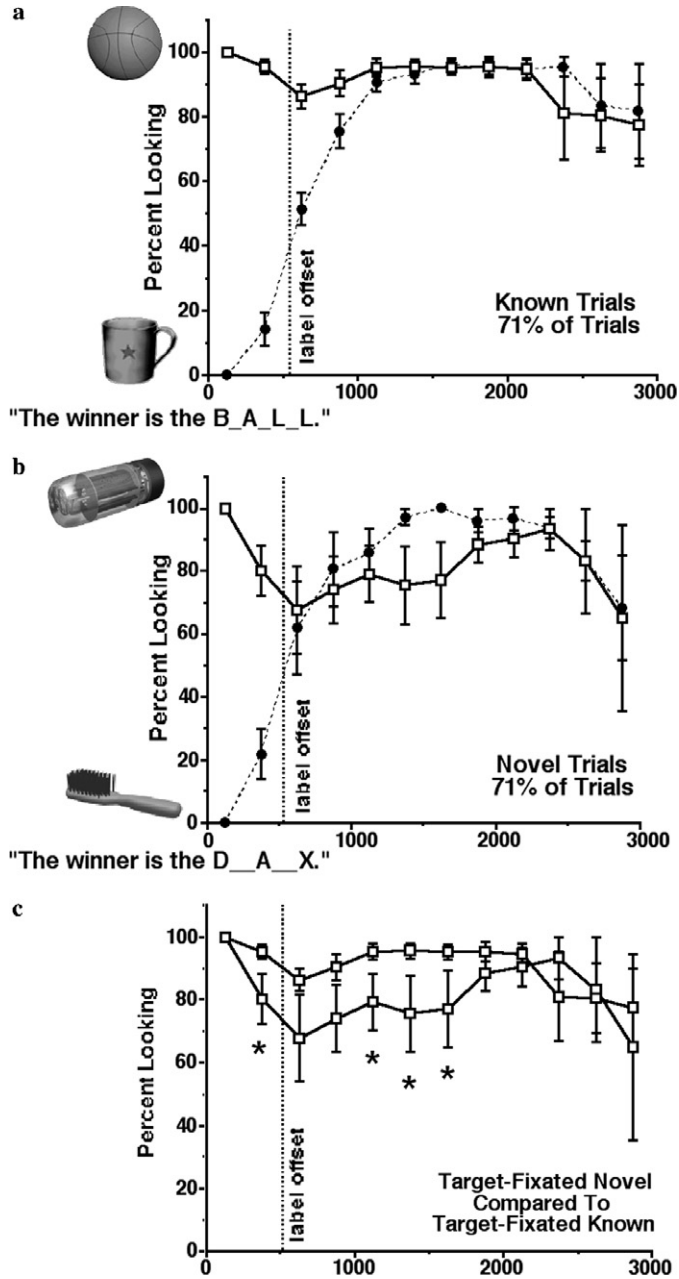


Fig. 16. Percent-lookup ( $\pm SE$ ) is displayed for only those trials on which participants had fixated both the target and distractor object prior to label onset (71% of all trials) in Experiment 3. At the time of label onset (0 ms) participants happened to be fixating either the target (open boxes) or the distractor (filled circles). Percent-lookup is displayed for Known (a), Novel (b), and Known and Novel combined (c). Preschooler significantly increased double-checking of the distractor on Novel compared to Known Label trials (c). \*Indicates  $p < .05$ .

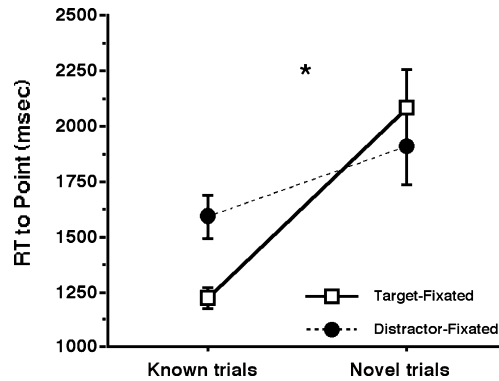


Fig. 17. Preschoolers' reaction time to point to the target object ( $\pm SE$ ) is displayed for Known and Novel Label trials as a function of which object (target or distractor) was being fixated at the time of label onset in Experiment 3. As predicted by Disjunctive Syllogism, the interaction is significant,  $*p < .005$ .

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-movements to potential target objects and reaction times to point to both known and novel referents suggest that both children and adults systematically reject known object distractors (e.g. brush) before mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube).

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 (i.e. A or B, not A, Therefore B), and the principles that may make use of this computational structure (Mutual Exclusivity, Contrast, and a Pragmatic Account), maintains that 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. While many details remain unspecified, participants in Experiments 1–3 appear to rely on information from the known object distractor (e.g. brush), *even when highly visually and conceptually novel objects were used as novel targets* (e.g. Fig. 1). This suggests that it is rejection of known objects that serves as the motivation for mapping novel labels to novel objects, but further experimentation will be needed to specify the details of the computations involved. For instance, it is an open question whether the behaviors revealed in the present experiments may be captured by parallel competition models of the lexicon (MacWhinney, 1987; McClelland & Elman, 1986; Merriman, 1999); or whether serial processing such as that involved in the comprehension of explicit and implicit negation will be required (Clark, 1974; Clark & Chase, 1974)? What is clear from the present results is that future models must be able to weight negative evidence (e.g. from known object distractors) more heavily than positive evidence (e.g. from visual novelty) when attempting to identify the referent of a novel label (e.g. “dax”). It is possible that the initial motivations behind the N3C principle may be maintained, but with a focus on the familiarity of the known object instead of the novelty of the novel object. By

analyzing the time required for participants to reject known object distractors on Novel Label trials (e.g. “dax”), and manipulating aspects of these distractors, one might discover that multiple sources of information are relevant, including: (1) that the object has a known name (e.g. “brush”), (2) that the object is visually familiar, (3) that the object is conceptually familiar, or (4) that the object is simple or complex. While the results presented here suggest that rejection of known object distractors (e.g. brush) is the rate-determining step for mapping a novel label (e.g. “dax”) to a novel object (e.g. phototube), one may find that information germane to multiple principles is important for motivating this rejection. This would engender a union of the motivations behind these principles (e.g. N3C, ME etc) within the computational framework of a Disjunctive Syllogism. Therefore, the present results take the form of a demonstration proof that: (1) children and adults have access to Disjunctive Syllogism, be it specific to word-learning or domain-general, and (2) they will utilize this deductive inference to learn new words.

Certainly, word-learners have access to multiple strategies. The method used in the present experiments, while very controlled, was not entirely natural. Use of Disjunctive Syllogism may be more likely in situations of a two-alternative-forced-choice task as used here. Such situations lend themselves to serial deductive strategies. In a more natural setting where multiple cues interact (e.g. direction of speaker’s gaze, objects in the near and far regions of space etc), it would be interesting to know how these computations may change. One possibility is that reasoning via Disjunctive Syllogism may only be engaged when the number of possible referents has been narrowed to 3 or 4 objects through the application of various constraints (e.g. direction of gaze). In an experiment similar to those presented here, I presented word-learners with 4 possible referents on Novel Label trials (e.g. “dax”) (Halberda, 2002). Results were consistent with Disjunctive Syllogism. 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).

Lastly, it is possible that different animals and different word-learners may rely on unique processes to attain the same goal. For instance, while a domesticated dog may show evidence of learning words by exclusion (Kaminski, Call, & Fischer, 2004; *for evidence from sea lions see Kastak & Schusterman, 2002*), it is possible that this animal uses an associative strategy rather than the Disjunctive Syllogism documented here for preschoolers and adults. While both domesticated dogs and young children will search for a hidden toy, dogs appear to rely on an associative strategy while young children use a deductive one (Watson et al., 2001). Differences across species and between individual human word-learners might be revealed using eye-tracking methods.

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. An exploration of the computations that implement such word-learning constraints is just beginning.



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