An eyetracking study of children's relational thinking: The role of labels and sustained attention

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Abstract

Relational match-to-sample is a difficult task for young children. However, it has been shown that either presenting two examples of the relation or adding a label to a single presentation can improve children's performance. The role of labels has been seen as increasing the likelihood of comparing the instances available. In this paper, we present sustained attention as an alternative to this view. Children completed a relational match-to-sample task in different conditions while an eyetracker registered their eye movements. When only one instance was available, children benefited from the addition of a label. This benefit was associated with an overall decrease in switching behavior, indicating greater sustained attention. Moreover, in the absence of a label, children who showed greater sustained attention were able to achieve good performance by the end of the task.

Keywords: relational matching; comparison; sustained attention; labels; language and cognition; eyetracking.

Introduction

Relational thinking is a fundamental activity of human cognition and everyday experience and might be uniquely human (Gentner, 2003). For example, knowing why both "left shoe goes with right shoe" and "left glove goes with right glove" entail a sameness relation transcends the properties of individual shoes and gloves. This kind of thinking involves going beyond superficial properties of stimuli and noticing the underlying commonalities and differences (Gentner, Rattermann, Markman, & Kotovsky, 1995). Relational thinking, however, is a developmental feat: early in life, children appear to categorize based primarily on perceptual features, and only begin to attend to the relational properties of the objects after four years of age (Gentner & Namy, 1999; Loewenstein & Gentner, 2005).

One typical task used to study relational thinking in children is the relational match-to-sample task (see Figure 1 for an example). In this kind of task, children are presented with an object that instantiates a relational property (the sample) and are then presented with two choices where only one matches the relational property instantiated by the sample. The youngest children in this task do not reliably pick the object that matches the relation depicted in the sample. The research reported here concerns two task manipulations that have been shown to increase relational matching in young children.

How to promote relational thinking: Compare instances

Multiple instances If given the right amount of support, children can succeed at the initially difficult task of relational match-to-sample. One way this can be achieved is by presenting multiple examples in the same trial (comparison). For instance, Christie and Gentner (2010) showed 3- and 4-year old children cards depicting the relation of sameness. Children saw either only one card (solo condition), or two cards simultaneously (comparison condition) or two cards sequentially (sequential condition). Only children who saw two sample cards simultaneously reliably picked the relational match between two choice cards. Multiple instances have been proposed to benefit relational reasoning by encouraging comparison of the instances.

The benefits of multiple instances have been shown many times in children in a variety of tasks (Gentner & Namy, 1999; Loewenstein & Gentner, 2001; Namy & Gentner, 2002; Oakes & Ribar, 2005; Pruden, Hirsh-Pasek, Shallcross, Golinkoff, 2008; Wang & Baillargeon, 2008) and also in adults (Gentner, Loewenstein, & Thompson, 2003; Gick & Holyoak, 1983). In the context of relational matching, "comparison" has two meanings: (1) the name of the task manipulation of the simultaneous presentation of another object that, although perceptually different, instantiates the same relation and (2) the presumed psychological mechanism that leads to better performance, that is, joint (or temporally close) inspection of the instances which fosters the discovery of deep relational similarities.

Label a single instance Another way to improve children's performance in the relational match-to-sample task is by labeling an original instance.

For example, Christie and Gentner (2007) presented 4- and 8-year old children as well as adults with only one sample instantiating the relation of 'sameness' and then asked participants to pick which of two options matched the sample. When the sample was not labeled, only the adults reliably picked another card instantiating sameness in this condition. However, when a label was added during the presentation of the original sample (e.g., "*Look, this is a truffet!*"), children reliably picked the relational match and even adults' performance improved. It has been proposed that labeling benefits performance through comparison, this is, that a label prompts people to compare the original

sample to each choice, and through this comparison they discover relations (Christie & Gentner, 2007; Gentner & Namy, 1999; Namy & Gentner, 2002).

In sum, presenting multiple instances, or labeling an instance, is hypothesized to invite comparison at some point during the relational match-to-sample task and this comparison supports successful relational matching.

A role for sustained attention?

The fact that two rather different manipulations – adding another instance and labeling one single instance – help children to discover matching relations should provide insight into a more precise specification of the processes (i.e., of comparison) that limit children's relational comparisons. Our working hypothesis is that each of these manipulations change how children visually inspect instances, perhaps when initially presented or during the difficult step of figuring out what choice to make. One possibility is that when multiple instances are available, children may establish links between the two samples by looking back and forth between them. They may also switch between these samples and the choice options, as they try to make their decision, which may also link the instances and choices and thus reveal the common relations (see Vurpillot, 1968). The process of switching among instances could be the critical behavior that highlights relational similarities between the objects and foster relational choices.

But why would a label encourage switching? The addition of a label to a single sample has been interpreted as inviting just this comparison process and more back-and-forth examination of the sample and choices, resulting in more links between the sample and the options and thus the discovery of the underlying common relation (Christie & Gentner, 2007; Gentner & Namy, 1999; Namy & Gentner, 2002). By fostering this sort of sampling, relational similarities can be discovered and children can successfully choose the relational match. Note that this hypothesized mechanism requires two steps: using a label leads to comparison, which then highlights relational features. The power of labels works only through comparison.

However this is not the only way that labels might work to promote relational matching. Using labels has been shown to improve performance across a great number of tasks other than making relational matches in both adults and children (Lupyan, Rakison, & McClelland, 2007; Waxman & Leddon, 2011; Vales & Smith, 2012). One leading possibility on why labels help is that labeling an object increases sustained attention (see Baldwin & Markman, 1989; McDuffie, Yoder & Stone, 2006). Sustained attention is generally good for learning in young children (Smith & Yu, 2013; Yu & Smith, 2012) and so may be critical to success in challenging tasks. That is, whenever children face challenges, if they can sustain attention to the relevant stimulus information they may be able to move beyond superficial or salient properties to the underlying structure. The power of labels could come, not from comparisons in the sense of back-and-forth looking, but from more sustained looking to individual stimuli.

A third issue important to understanding how comparison works concerns how performance changes across trials in the task. The two presented hypotheses concern what happens in a single trial. But relational-matching experiments present children with a series of trials that present, successively, instances of the same relation. By definition, successive presentation does not involve direct comparison, but if children remember what they have seen in previous trials, then comparison to items in memory becomes a factor that may affect either back-and-forth comparison or sustained attention. Critically, past research has shown that there can be accrued effects across trials that influence children's relational matching (Gentner, Loewenstein, & Hung, 2007; Kotovsky & Gentner, 1996).

The main goal of the current experiment was to test the competing hypotheses about the power of labels to promote relational matching: Either they increase (switch) or decrease (sustain) the rate that children visually sample available information.

If labels work through sustained attention, then we might also see improved performance when sustained attention is present in other ways. In order to detect this, the experiment includes both Multiple and Single instance conditions. The Single No Label instance condition is critical to our analysis as to the best of our knowledge, no research has reported that young children can successfully match relations when they see only one unlabeled instance on each trial. However, labeling this single instance has been shown to dramatically improve performance.

In the case of unlabeled single instances, children might need to accumulate enough evidence to allow them to understand the relation being instantiated across trials. They might only do so if they show sustained attention. Do children who show sustained attention over several trials reach the same level of success as children who got a single labeled sample?

To answer these questions, we designed a novel eyetracking relational match-to-sample task. To examine how labels and sustained attention matter for relational matching over time, we analyzed children's performance across eight trials. To capture how children sample visual information in different conditions, we used eye-tracking technology. We included a full set of four conditions: multiple or single sample, with or without label. As in previous studies, conditions with multiple exemplars (both labeled and unlabeled) should support relational matching. We included these conditions to show that our novel paradigm replicates well-known effects.

By considering learning over time as well as finer-grained measures of visual sampling, this study offers novel insight into the role of labels in children's relational thinking.

An Experiment

Method

Participants Fifty-eight children (M = 54 months, range = 42-68 months) were randomly assigned to one of four conditions: Multiple presentation without label, Multiple presentation with label, Single presentation without label, Single presentation with label. Twenty additional children were recruited but not included in the final sample due to inappropriate calibration, missing video data, refusal to complete the task or eye tracking data missing for more than half of the total number of samples. Children had no known developmental disorders and were reported to have normal (or corrected to normal) visual acuity. Parental consent was obtained for all participants in compliance with the IRB of Indiana University.

Apparatus and procedure Children were seated approximately 211cm from a 55'' LED screen. A free-standing Tobii X120 eye tracker (Tobii Technology BA, Stockholm, Sweden) was used to capture children's eye movements at 60 Hz sampling rate. E-Prime software (PST, Pittsburg, PA) was used to control stimuli presentation and to record eye gaze data. Before starting the main experiment, children completed a 9-point eyetracking calibration that was followed by a familiarization to the structure of the task. The main experiment included 8 trials, and each trial consisted of an Exposure phase followed by a Choice phase (see Figure 1). During the Exposure phase, children saw either one exemplar of a same-relation (Single Conditions) or two different exemplars of a same-relation (Multiple Conditions) on the top half of the screen. A pre-recorded voice oriented children to the exemplar(s). In the Single No Label condition this prompt was "*See this one?"* or "*This is one"*. In the Multiple No Label condition we added to the prompts of the Single condition the following prompts: *"See this one too? See how they are the same kind of thing?*" or *"This is one too. They are both the same kind of thing!*".

In the Label conditions, on each trial the pre-recorded voice said the name of the Target during the Exposure (e.g. "*See this dax?" / "See this dax too? See how they are both daxes?*" and "*This is a dax" / "This is a dax too. They are both daxes!*"). A different label was used on each trial (dax, ryke, fode, pabe, zup, kiv, mell or cheem), with target-word assignment randomized across participants.

After the original instance(s) were presented, two new exemplars appeared on the bottom half of the screen for the Choice phase: one same-relation (Target) and one different relation (Foil). Children were asked to point to the choice that was "the same kind of thing" (no label conditions) or "another {dax}" (label conditions). Across trials, the Target appeared equally often on the left and right side of the screen. There was no time limit for children's response. The prompts used throughout the experiment were recorded by a female native English speaker at a sample rate of 44.1 KHz.

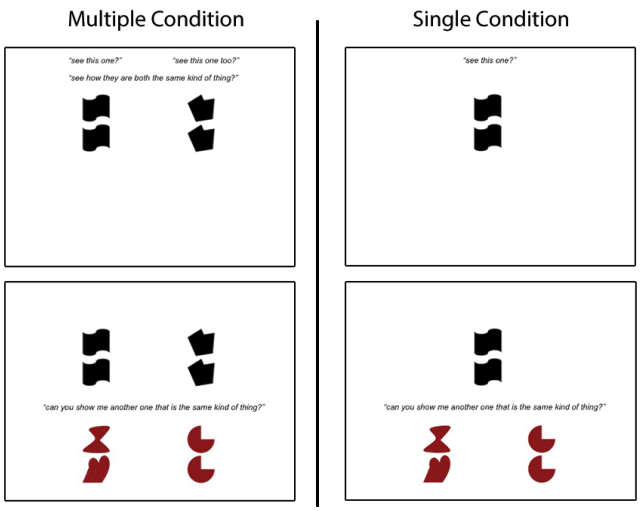

Figure 1: Schematic representation of the structure of a trial in the multiple and single conditions without label. In the label conditions prompts had a unique label for each trial. The top row represents the Exposure Phase and the bottom row the Choice Phase. Example prompts are presented in the picture for illustration purposes only and were not presented to children.

Results

Accuracy Did children successfully find the relational match? In the first four trials, the pattern of responses is consistent with prior findings (see Figure 2). Specifically, children performed above chance when given multiple instances (No Label: $M = .65$, $t\ (14) = 3.16$, $p = .007$; Label: $M = .62$, $t\ (15) = 1.94$, $p = .07$) and also when a single instance was labeled ($M = .63$, $t\ (15) = 2.18$, $p = .04$). Children who got a single unlabeled instance did not reliably choose the relational match ($M = .51$, $p > .05$). Thus as in previous research, both multiple samples and labels support relational matching.

We then analyzed performance during the last four trials of the task to examine if children are able to establish relational matching over several trials. In the second half of the task, only one group of children performed above chance. Children who got single *unlabeled* instances throughout the task learned over the course of the task and successfully found relations ($M = .63$, $t\ (14) = 3.16$, $p = .007$). Thus, performance did *not* get better over trials but declined in the multiple samples conditions and improved in the condition usually associated with the poorest relational matching in young children. On the last of the experiment, the single unlabeled condition yielded the highest performance.

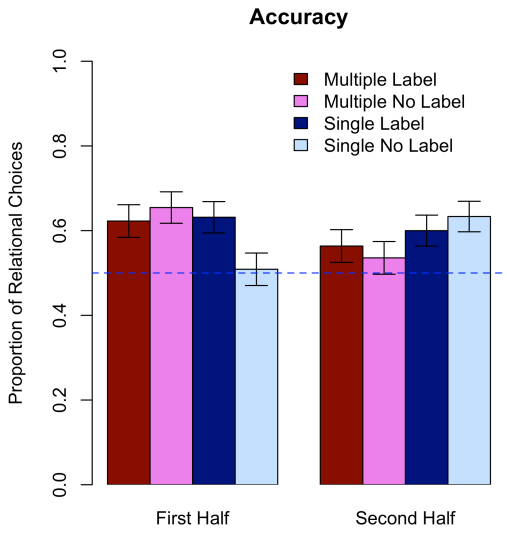

Figure 2: Proportion of relational choices for each condition across the task. The dotted line represents chance performance in the task.

Sampling of information How did children sample the visual information that was available to them when making a relational match-to-sample decision? One of the hypotheses for the benefit of labeling in the Single condition is that labels encourage children to compare the sample with each of the choices. An alternative hypothesis is that labels increase sustained attention to each instance. Critically, these two hypotheses make opposite predictions about the number of switches between the sample and choice options: the label either increases switching (more comparing) or the label decreases switching (more sustained attention).

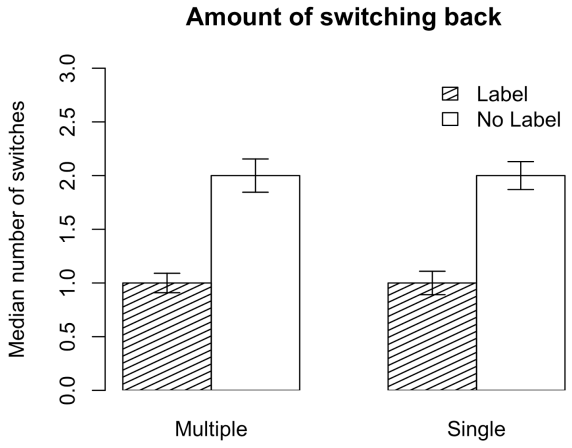

Figure 3: Median number of switches back to the original instances during the choice phase for each condition.

Accordingly, we analyzed how often children switched back to the original sample(s) while they made a decision in each condition (Multiple or Single) in the presence and absence of labels. The results are clear: Children switched *less* when instance(s) were labeled (see Figure 3).

Adding a label reduced considerably the number of switches for both presentation conditions. An ANOVA looking at the mean number of switches with label condition (Label vs. No Label) and condition (Multiple vs. Single) as between-subject factors revealed a main effect of label, $F(1,54) = 4.74$, $p = .03$, and no main effect of condition, $F(1,54) = 1.86$, $p = .18$ or interaction between the two, $F(1,54) = 1.31$, $p = .26$.

These results are consistent with the sustained attention hypothesis: Less switching would be associated with greater sustained attention on each object. Could sustained attention also be critical for learning over time, as children in the unlabeled Single condition did?

To answer this question we divided children in the Single No Label condition into two groups based on how much children switched from the options back to the sample during the first half of the task. Children who switched back more than the median for the sample were considered "High Switchers" while the remainder was considered "Low Switchers". If the benefit of time in the Single No Label condition were associated with sustained attention during the initial part of the task, Low Switchers would show better performance in the second half compared to High Switchers. Indeed, children who showed sustained attention during the initial learning trials were the children who learned over the task (see Figure 4).

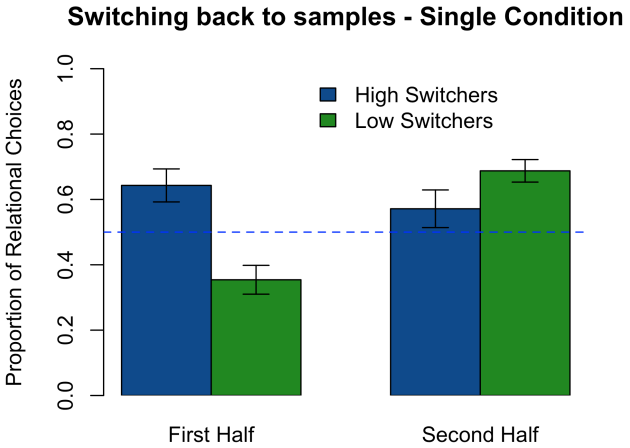

Figure 4: Proportion of relational choices for the Single No Label conditions across the task as a function of the amount of switching back to the original instances while making the choice. The dotted line represents chance performance in the task.

Although less switching in this condition during the initial part of the task *does not* result in better performance during

that part of the task it does seem to be associated with improved relational matching performance by the second half of the task. Indeed, only performance of Low Switchers on the second half of the task was significantly above chance levels, $M = .68$, $t(7) = 3$, $p = .02$. Moreover, this group's improvement from performance in the first half ($M = .57$) to the second half is also significant, $t(7) = 2.78$, $p = .03$.

Discussion

Can sustained attention play a role in relational thinking? In answering this question, we need to take into consideration how children sample the information presented and what are the dynamics between sampling and sustained attention.

In the present work we aimed to investigate this question in the context of children's relational thinking – an important cognitive tool in human development. We asked children to match one of two options to a sample relation by visually inspecting the objects. The inclusion of labels, which have been shown to enhance relational matching, did so in the present study on early trials (but not later ones) and also led to more sustained looking and less switching.

Performance in the one-instance condition was particularly informative. This condition has been shown to be particularly challenging to children. Furthermore, to measure children's sampling and attentional behavior we used eyetracking technology. This method allowed us to gain initial knowledge on the dynamics of single presentation of evidence, labeling and relational matching. The evidence from the present work shows that relational match-to-sample performance is related to accumulation of evidence, effective sampling of information and sustained attention.

Behaviorally, the results presented here replicate previous evidence that single presentation of an instance of the relation does not provide enough support for children's relational thinking without the addition of a label. However, if we analyze the progress of children's performance across the task, we see that even in the absence of a label, children in the single condition can achieve above chance performance.

Accumulation of evidence Children who are presented with multiple initial instances of the target relation are more likely to choose the relational match from the beginning. Conversely, children who are only presented with one instance of the target relation in each trial require more trials to achieve this level of performance. Thus, learning the relational structure of objects requires children to relate several instances of the target relation. This can be more easily done when two instances are presented in each trial (Multiple condition).

Our results show that children in the Single No Label condition were able to achieve above change relational match behavior by the end of the task. However, only children who switched less from the choices back to the sample were able to achieve higher levels of performance by the second half of the task. This indicates a role for both accumulation of evidence and sustained attention on performance in a relational match-to-sample task.

Focal attention and effective sampling Overall, adding a label to the presentation of the original instances decreases the mean number of times children check back to the original instances. This result is in line with previous evidence that labels increase sustained attention to objects (Balaban & Waxman, 1997; Baldwin & Markman, 1989; Fulkerson & Waxman, 2007, McDuffie, Yoder & Stone, 2006). This increased attention to each object is essential for a better identification of the target relation, particularly when the support from multiple samples is not readily available (the Single conditions).

In sum, the present work demonstrates the important role of sustained attention in learning how to make a relational choice when only one sample is presented. When a label is present in this condition it will increase sustained attention and result in better, faster, learning. In the absence of learning, sustained attention is important in the accumulation of evidence across several individual trials.

The importance of sustained attention is evidently dependent on some switching between the objects to establish relevant links among them. However, it does show an alternative to the hypothesis that comparison involves greater amounts of switching between samples and that labeling improves performance by promoting comparison.

At present, the specific mechanisms that underlie the usual positive effects of simultaneously presented multiple instances, labeling, and accrued effects of repeated trials have all been explained under the rubric of "comparison". The present approach – seeking micro-level behavioral evidence of direct comparison – suggests that all these phenomena are not the same. By pulling these factors that benefit children's relational matching apart, we may get a better handle on the processes that limit relational matching and on just what "comparison" is.

Accordingly, we believe the biggest contributions of the work presented here is the use of a new analysis paradigm to the investigation of comparison benefits to learning across development and the introduction of sustained attention as an important player in relational thinking.

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